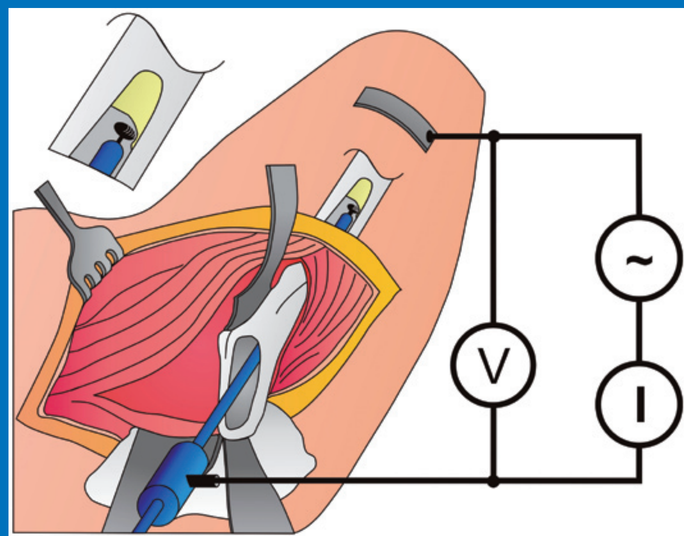
medIT

Medical Information Technology

Faculty of Electrical Engineering and Information Technology



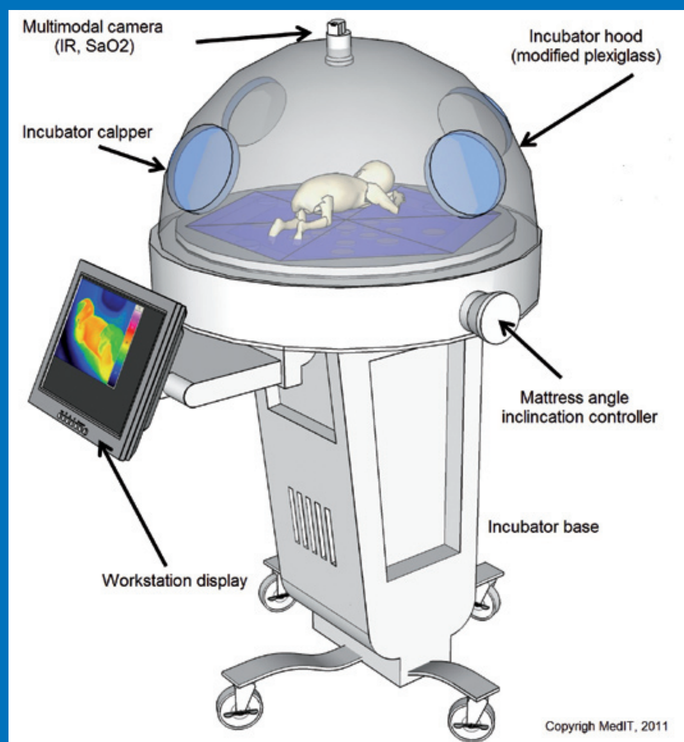
Smart Solutions for Advanced Healthcare

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
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
Balzer-Sy, Heidi, Admin. Assistant
Clever-Offermanns, Bettina, Admin. Assistant
Wrobel, Walter, Dipl.-Ing., Laboratory Engineer
Gerle, Melanie, IT Administrator
Voigtländer, Paul

Abbas, Abbas, M.Sc.
Blanik, Nikolai, Dipl.-Ing.
Brendle, Christian, Dipl.-Ing.
Brüser, Christoph, Dipl.-Ing.
Cordes, Axel, Dipl.-Ing.
Eilebrecht, Benjamin, Dipl.-Ing.
Foussier, Jérôme, Dipl.- Ing.
Fu, Xiaogang, M.Sc.
Gerlach-Hahn, Kurt, Dipl.-Ing.
Glöggler, Sigrid, Dipl.-Biol.
Heinke, Stefanie, Dipl.-Wirtsch.-Ing.
Hülsbusch, Markus, Dr.-Ing.
Ismail, Abdul Hamid, M.Sc.
Kim, Saim, Dipl.-Ing.
Köny, Marcus, Dipl.-Ing.
Krause, Inga, M.Sc.
Lunze, Katrin, Dipl.-Ing.
Pikkemaat, Robert, Dipl.-Ing.
Pomprapa, Anake, M.Sc.
Röthlingshöfer, Lisa, Dipl.-Ing.
Schlebusch, Thomas, Dipl.-Ing.
Schommartz, Antje, Dipl.-Ing.
Teichmann, Daniel, Dipl.-Ing.
Ulbrich, Mark, Dipl.-Ing.
Venema, Boudewijn, Dipl.-Ing.
Wartzek, Tobias, Dipl.-Ing.

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Introduction

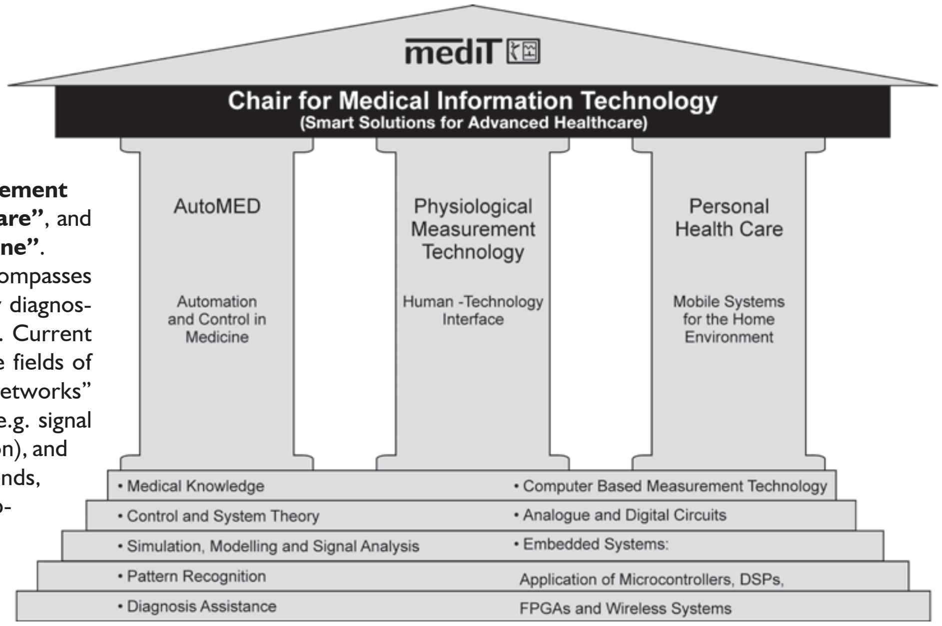

Fig. 1: Research profile of MedIT.

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 artefact 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 modelling and implementation of feedback controlled therapy techniques. Research topics include tools and methods for the modelling of disrupted physiological systems, sensor supported artificial respiration, active brain pressure regulation, and dialysis regulation and optimization.
Where necessary and sensible, we also develop sensors and measurement electronics, for example, in the areas of non-contact sensing techniques (e.g. magnetic bioimpedance), bioimpedance spectroscopy and inductive plethysmography. We are also active in biomechatronics.

Selected Ongoing Research Projects

LAVIMO- Long Term Monitoring of Vital Signs by In-Ear Sensor

Cardiovascular diseases are among the most common causes of death in western industrial nations. Therefore, early determination of the cardiovascular risk factor is necessary in order to take preventive measure. The LAVIMO (Long Term Monitoring of Vital Signs by In-Ear Sensor) project aims to assess cardio-vascular functionality using photoplethysmographic signals acquired from an in-ear sensor. By long-term monitoring of vital signs such as heart rate or respiration, it provides a comprehensive personal health care system which can also meet the daily patient's requirements of mobility, usability and robustness.
Photoplethysmography (PPG) is an established method for non-invasive investigation of subdermal perfusion. Since common systems use a transmissive measurement method, i.e. light is transmitted through the tissue, only slender parts of the body like finger tip or ear lobe can be used. As a result, this measurement method is impaired by centralization and motion artifacts and therefore not applicable for long-term monitoring of "at-risk" patients at home.
LAVIMO is based on an alternative solution, the "reflective PPG sensor", which can be placed in the auditory canal. This allows a 24/7 measurement with particularly high wearing comfort. The central component is a micro-optic reflective sensor, which is sealed within a biocompatible otoplastic housing. 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). Pre-clinical trials in humans indicated that cardiac and respiratory activities can be measured with high accuracy.
In the near future, we believe that such optoelectronic sensing strategies will be found in a wide range of applications, as ambient assisted living and telemedicine.
Funded by: German Ministry of Education and Research (BMBF)

Fig. 2: Miniaturized optoelectronic in-ear sensor.

SmartLifeSupport – HeartControl

Many patients with sever cardiac insufficiency survive under the aid of Ventricular Assist Devices (VAD) or Total Artificial Hearts (TAH). The former ones support the native heart, whereas TAHs replace the native heart except for the atria.
The “HeartControl” project aims to realize adaptive physiological control algorithms for the VADs and TAHs. Prior to implantation of devices into humans, pre-trials on a test stand (Mock Circulatory Loop, MCL) and animals are required in order to assure operational reliability and efficiency.
A MCL mimics the hydraulic load which the device is exposed to after the implantation. Most MCLs are composed of passive elements (e.g. hydraulic resistances and capacitors) to account for the RC-behaviour of vessels. As a result, these “classical” MCLs operate only at fixed operating points. Furthermore, simulating transitions between variable cardiac conditions, e.g. between resting and exercise is not possible.
As an alternative, we have developed a MLC with actively controlled electro-hydraulic elements as the key components. DC-motor driven gear pumps are simulating variable resistance and valves. Consequently, neither check valves nor actively controlled valves are required in our MCL to mimic heart valve properties. Water hammer effects and other undesired artefacts are mitigated. Metal bellows driven from Voice Coil Actuators (VCA) are simulating capacitors in order to mimic the compliance of vessels and ventricles. Finally, two gear pumps and one VCA driven metal bellow are combined into compartments that enable the simulation of actively controllable complex hydraulic impedances. Up to now, two compartments have been built to apply various pre- and after-load conditions to the devices. The set points for the compartments are derived from a computer simulation of the cardiovascular systems. Such a hybrid cardiac simulator (Fig. 3) would enable successful technical / reliability assessment of VADs and TAHs under various physiological conditions.
Funded by: German Research Foundation (DFG)

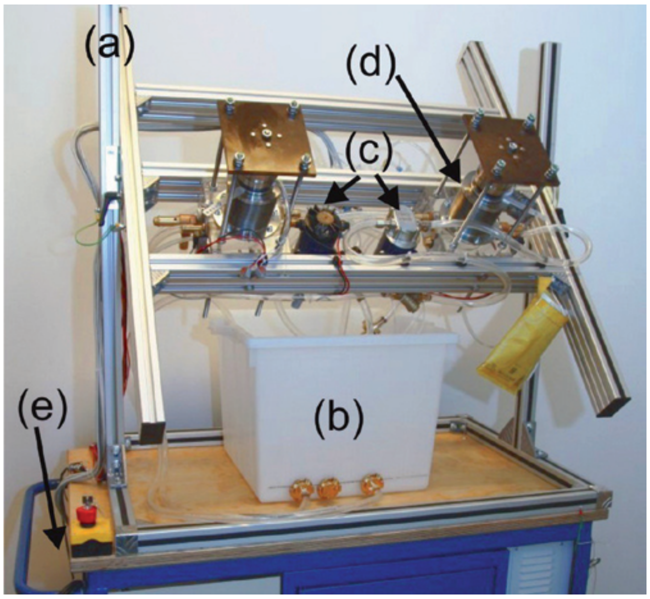

Fig. 3: Test stand, (a) rack, (b) tank, (c) gear pumps, (d) VCA, bellow combination, (e) roll cart.

Control of Intracranial Pressure – towards an “intelligent Shunt”

The human brain is immersed in the so-called Cerebrospinal Fluid (CSF), which protects the brain from mechanical stress (e.g. concussion) and serves as a nutrient supply for 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 catheter system (called “shunt”) which drains excess fluid into another body compartment (usually the abdominal cavity).
Every year, more than 18000 patients in Germany obtain a shunt; however, the complication rate of 50% is quite high. One of the biggest problems is the mismanagement in the drainage. Although a persistent elevated Intracranial Pressure (ICP) can be fatal, a too high drainage is not healthy either.
To prevent high drainage due to artefacts in ICP, which can occur for example while coughing and moving, and to give the doctor information about the success of the therapy and alert him when the shunt is blocked, an intelligent shunt has to be developed. Furthermore, a mechatronic valve needs to be developed to control the liquor drainage. As a first step towards an intelligent shunt, an external drainage has been developed which can adapt the liquor drainage of patients suffering from high ICP. Next step will be signal analysis of ICP dynamics and the development of algorithms to control the liquor drainage intelligently according to the condition of the patient.
Funded by: German Ministry of Education and Research (BMBF), START, Holste Foundation

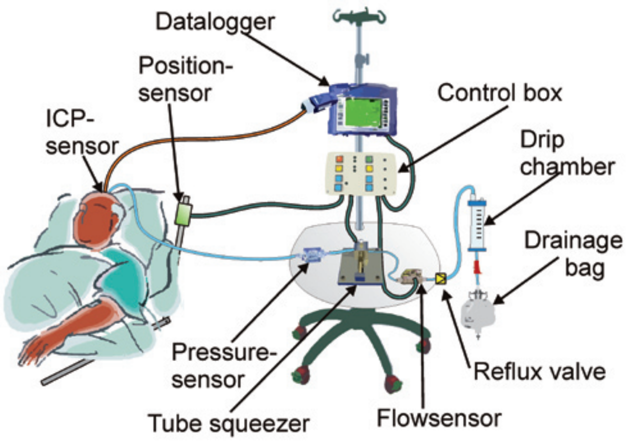

Fig. 4: Control of liquid flow within the external drainage.

Neonatal Contactless Temperature Monitoring based on IR Thermography Imaging (NIRT)

Temperature measurements of newborn infants during the incubation period is vital and a major aspect in regular Neonatal Intensive Care Unit (NICU) procedures. Therefore, developing a non-invasive and optimal temperature monitoring method is important for the neonate’s

clinical care. The primary scope of the NIRT project will lead to the development of an incubator that responds to any physiological and pathological disturbance on neonatal status in a robust and stable way. Additionally, it will investigate the efficiency of using a non-contact thermography system as a new diagnostic tool for newborn babies. Blood perfusion and respiration will be remotely monitored with infrared thermography imaging by tracking the Region of Interest (ROI) over the nasal region and identifying heat loss as a thermal signature between inspiration and expiration phases. The project consists of different work packages, which includes modeling the thermoregulation process, designing an adaptive control unit, and prototyping virtual temperature sensor(s) for NICU.
In the future, the Know-How achieved in studying neonates' infrared thermography methods will assist pediatricians to identify heat and cold stress effectively, even during the influence of external factors as opening the incubator door.

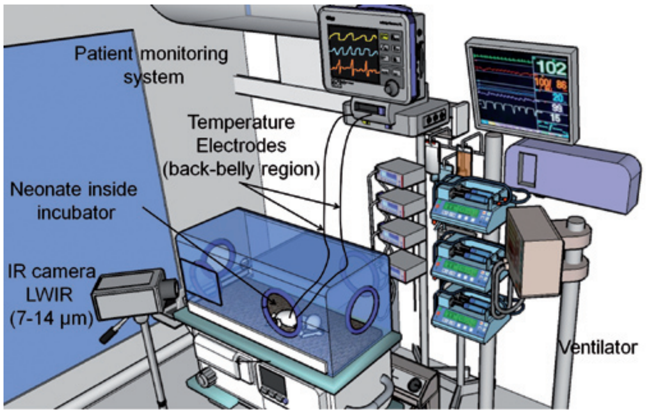

Fig. 5: Concept of NIRT system.

Non-Invasive Hemodynamic Monitoring

Cardiovascular diseases are the most common cause of death in Western Europe. One of these diseases is Chronic Heart Failure (CHF) from which over two million people are suffering. Measures for these dysfunctions are hemodynamic parameters, i.e. Cardiac Output (CO) or Stroke Volume (SV). Till now, the gold standard method for measuring these parameters is thermodilution, which is a non-invasive procedure involving a pulmonary artery catheter. However, using a catheter for estimating CO is usually associated with high risk of infections, sepsis, and arrhythmias, as well as increased morbidity and mortality. Some clinical measuring methods, as echocardiography, manage to overcome these problems. Nevertheless, they are not suitable for home care monitoring scenarios.
Impedance Cardiography (ICG) provides a promising alternative for non-invasive evaluation of these parameters using bioimpedance spectroscopy. Based on that, a part of this project will lead to the realization of a textile-integrated bioimpedance measuring system which allows the monitoring of hemodynamic parameters non-invasively by the patient himself at home. Among other things, finite element simulations would be conducted using dynamic MRI data concerning heartbeat to analyze the origin of the signal. These simulations allow the systematic evaluation of several measurement scenarios in a short time and theoretically validate the obtained results.
Funded by: EU project HeartCycle

Fig. 6: Impedance cardiography (ICG) measuring system.

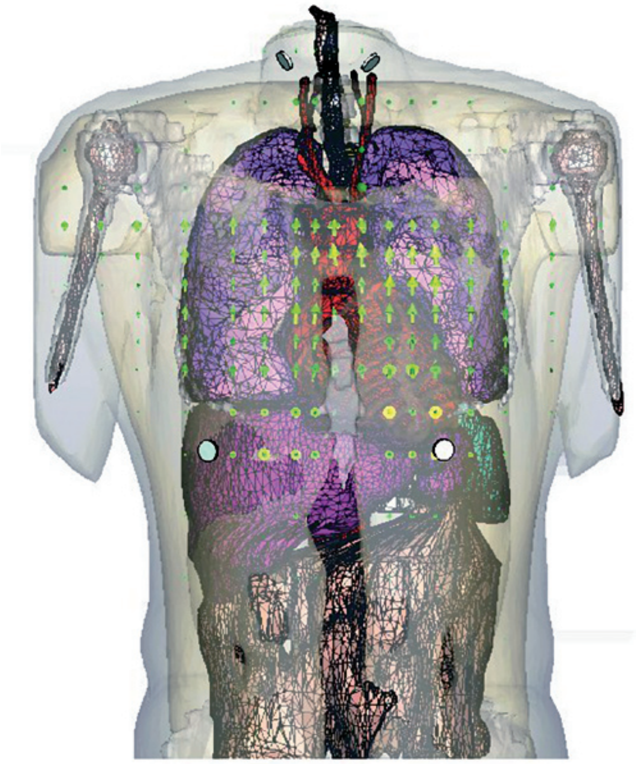

Fig. 7: Finite element simulation of the human body.

Intelligent Toilet Home Monitoring Appliance

To ensure high quality of health care in a society with growing fraction of elderly, an "intelligent toilet" has been developed for monitoring health status especially for those with diabetes mellitus type II or chronic heart diseases.

Heart rate, body weight and composition, temperature, extremity perfusion, and urine-glucose levels are evaluated in a fully automated manner at regular basis while maintaining the simplicity of a conventional toilet. These data will be daily sent to remote physicians for further diagnostic purposes.

Weight distribution of voluntary sitting on a toilet seat has been analyzed to develop a suitable toilet seat electrode concept. Our pressure measurements showed distinguish patterns for male and female subjects. Based on these patterns, the optimum electrode position, which provides good contact for subjects of both genders, has been chosen. For embedding in the selected position, dry electrodes have been designed using an electrode test rig previously developed at MedIT. Preliminary results showed that best electrode contact can be obtained using gold plated electrodes integrated in the side part of the toilet seat (Fig 8).

Both ECG and Bioimpedance Spectroscopy (BIS) measurements were performed using these electrodes and the results were compared with those obtained by standard hydrogel electrodes. For ECG measurements, a high gain amplifier was necessary. Initial results showed clearly visible R-peaks in the recorded signals; however, all other details are concealed in noise, and so further signal processing is still necessary. As a reference measurement, a BSamp biosignal amplifier (g.Tek, Austria) has been used.

Subject's weight is measured using a multilayer toilet seat with integrated force sensor to measure the weight on the seat, while an additional foot rest in front of the seat accounts for the weight of the legs. For urine analysis, a unit developed by our project partner is integrated.

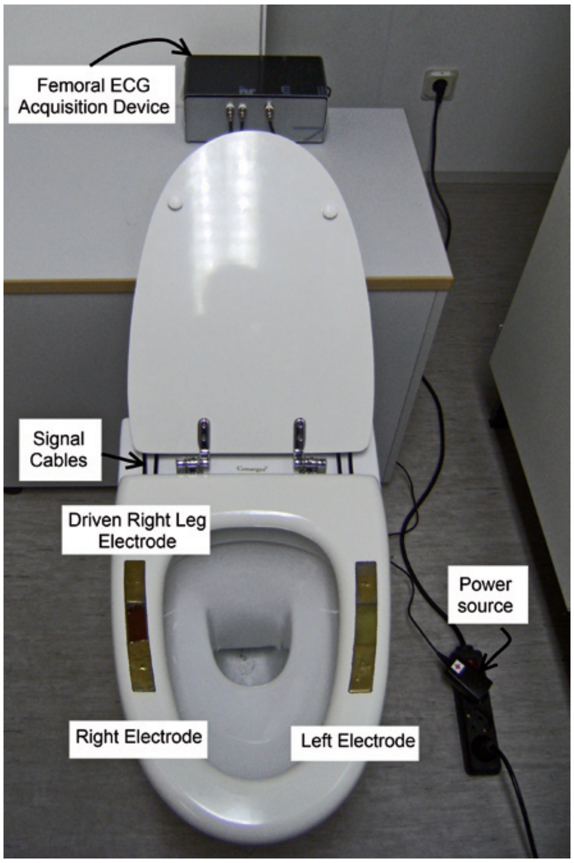

Fig. 8: Concept of intelligent toilet.

It automatically samples urine from the bowl and analysis colour, opaquemess, and other parameters by using colour indicator strips.

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

SensoPal – Sensor-integrated Patient Bed

The goal of this joint project together with MediTEC and SurgiTAIX is the development of an innovative patient bed with integrated sensors which allow a contactless measurement of the electrical heart activity and a magnetic tracking of instruments and catheters. The magnetic tracking system is integrated (by MediTEC) under the patient bed and does not need any line of sight, thus allows the tracking of instruments inside of the body. Due to the contactless integration of sensors for the vital signs and the magnetic tracking system, efficiency is increased and possible errors in standard procedures due to disturbing cables are reduced.

Figure 9 shows the capacitive electrocardiogram (cECG) sensors which are integrated into a mattress overlay. Due to the very flat construction of the sensors, they are very comfortable for patients. The measurement system will automatically choose the array of sensors which have the best contact to the patient lying on the bed. This allows ECG measurements independent of the individual lying position. Since the contactless measurement inherently results in more motion artifacts, a new optical sensor is additionally integrated into the sensors. Our results recently showed that artifacts result mainly from relative movements of the sensor with respect to the body where so called triboelectric effects occur. Together with the optical sensor, which detects relative movements of the subject, and a complex signal processing, motion artifacts are considerably removed and a robust estimation of heart rate is possible. A final post-processing with a medical expert (or decision) system is implemented to reduce false alarms and workload for medical staff.

Hence, with an unobtrusive monitoring and a medical expert system this project increases patient safety, also in environments where only low monitoring by medical staff is present and affordable (e.g. general ward).

Funded by: Ziel2.NRW

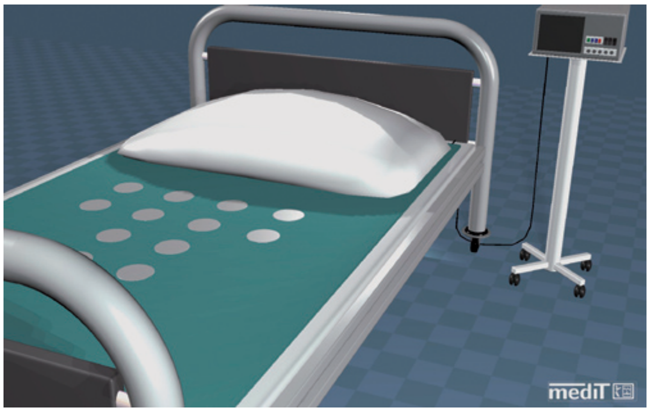

Fig. 9: cECG sensors integrated into a mattress overlay.

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Prizes and Awards

- C. Brüser: Springorum-Medal, RWTH Aachen.
- M. Hülsbusch: SENSOR Innovation award 2010 for "In-Ear Sensor for Vital Parameter Monitoring".
- S. Leonhardt: Stipend of the Heinrich-Hertz-Foundation, Düsseldorf, for a research stay at Imperial College, London, UK.
- T. Schlebusch and T. Wartzek: 2nd and 4th place respectively at DGBMT student contest.

People at MedIT

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