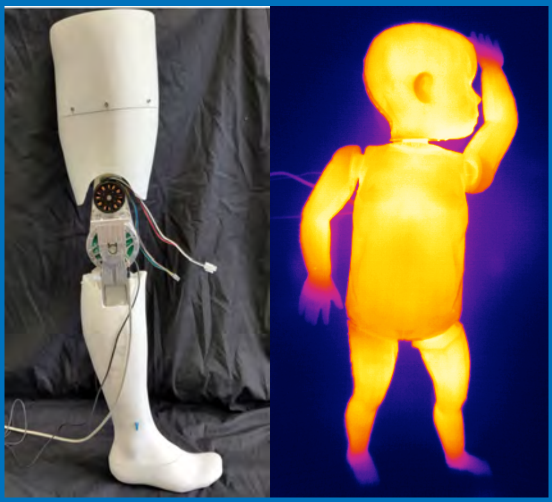
medit | RWTH AACHEN UNIVERSITY

Medical Information Technology

Faculty of Electrical Engineering and Information Technology

Smart Solutions for Advanced Healthcare



Director

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Glöckner, Daniele, Secretary
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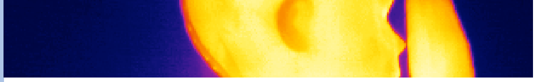
Trödel, Cedric, Software Developer
Warkentin, Astrid, Software Developer
Weike, Katharina, Software Developer

Guests

Prof. Stefan Borik (UNIVERSITY OF ZILINA) visited the chair from the 1st of July to the 31st of October 2022.



Introduction

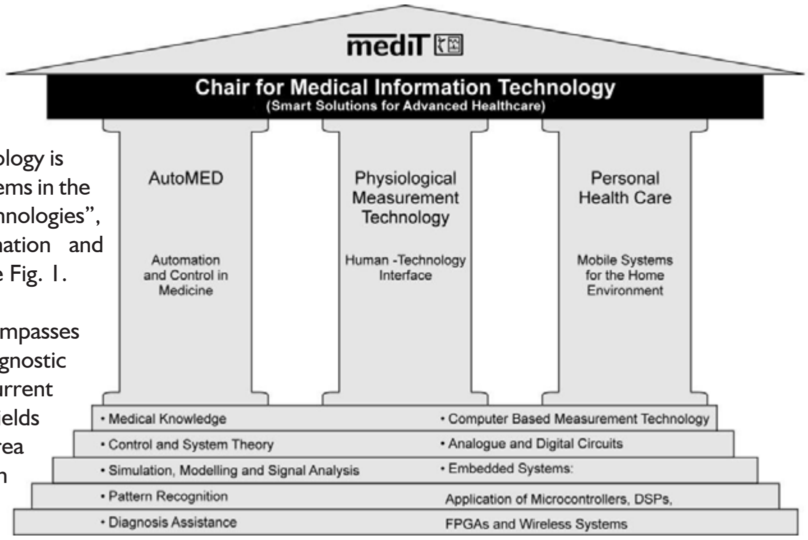


Fig. 1: Research profile of MedIT.

The Chair for Medical Information Technology is especially concerned with research problems in the fields of "Unobtrusive Measurement Technologies", "Personal Health Care", and "Automation and Control in Medicine". For illustration, see Fig. 1.

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, our chair 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, unobstrusive measurement technologies (sensors and 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.

Ongoing Research - Selected Projects

Camera-based Early Detection of Blood Poisoning in preterm infants

The occurrence of sepsis in preterm infants is one of the most critical complications in the neonatal intensive care unit (NICU) and poses a major threat to mortality and long-term morbidity. Due to the rapid progression, the mortality rate increases by 7.6 \% every hour in which the therapy is delayed. Therefore, advanced monitoring systems are crucial for an early prediction of the sepsis onset.

Today, various vital parameters are recorded using contact-based measurement techniques such as ECG and PPG. In this context, the immature skin of the preterm patients and the associated inefficient barrier to the environment are major issues, because the infant can be additionally injured or infected during the replacement of the adhesive electrodes. The use of non-contact techniques for continuous monitoring of vital signs can facilitate the situation for both the medical staff and the patients by measuring the medical parameters without direct skin contact with camera-based devices. These systems could therefore reduce the prevalence of diseases such as sepsis. By using a camera-based system for vital parameter monitoring, the first signs of septic shock could be detected automatically.

The project SIRIO focuses on the fusion of two unobtrusive measurement techniques, Photoplethysmography Imaging (PPGI) and Infrared Thermography, which can be applied in the NICU, see Fig. 2. While PPGI enables the recording of heart rate and perfusion in the tissue and additionally a quantification of the microcirculation, Infrared Thermography indicates the radiation of the body's own heat of the patient. This allows local temperature distributions and central-peripheral gradients to be recorded and analyzed for sepsis prediction. Furthermore, the system could enable the monitoring of respiration rates and physical activity, which provides further information about the medical condition. In combination with data-driven Deep Learning-based algorithms for real-time image processing, the data fusion of the camera system enables the derivation of an early warning parameter directly at the incubator. Therefore, an early start of therapy can be realized, which significantly improves the healing and survival chances of neonatal patients.

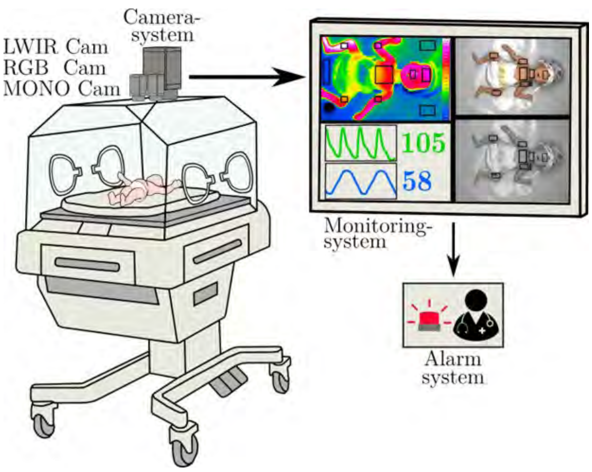
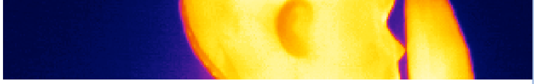


Fig. 2: Schema of the SIRIO project, combing Photoplethysmography Imaging (PPGI) and Infrared Thermography.

Funded by: German Research Foundation (DFG)



Non-invasive Monitoring of the Peripheral Arterial and Venous Oxygen Saturation with contact-based and camera-based Photoplethysmography

Deficient oxygenation in tissues causes hypoxic cell damage, which is critical in vital organs such as the heart and brain. Under normal physiological conditions, oxygen delivery and consumption relate to each other; however, microcirculatory dysfunctions such as diabetes mellitus and sepsis can alter the cohesion between oxygen supply and consumption. Thus, determining these factors is crucial for the 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 arterial and venous blood to estimate oxygen saturation and further detect circulatory diseases. For that, photoplethysmography (PPG) is used, a technique in which the skin is illuminated with two specific wavelengths to distinguish the absorbing properties of oxygenated and deoxygenated hemoglobin. PPG is obtained through contact-based sensors and through video images from a commercial webcam, which works as a PPG sensor that captures reflected red, green, and blue light. The novelty of our technique to monitor venous blood relies on the „venous muscle pump", which considers dorsal ankle extensions at a fixed frequency for generating easily identifiable venous blood volume variations, see Fig. 3.

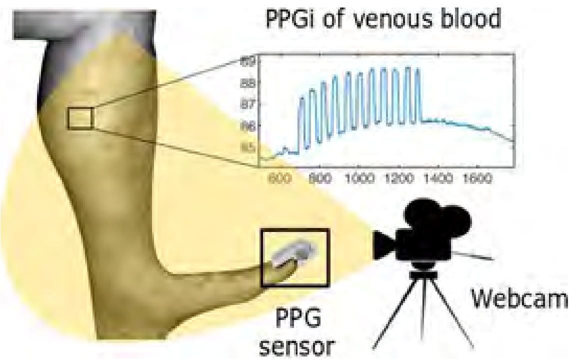


Fig. 3: Venous blood volume variations acquired through a contact-based PPG sensor and a commercial webcam during the „venous muscle pump test" (dorsal ankle flexion) to estimate the venous oxygen saturation.

Several aspects are investigated within this project. Firstly, image and signal processing are needed to acquire the PPG signals of arterial and venous blood pulsations, plus filtering and a removal of motion artifacts, through conventional and machine learning-based algorithms. Secondly, physiological and mathematical models based on Monte Carlo simulations need to be developed to estimate the oxygen saturation from the signals. Besides, a pressure cuff placed on the calf/finger can be controlled through a self-made hardware system to artificially generate venous blood pulsations at a regulable frequency and pressure. Finally, the arterial and venous blood circulations must be simulated on a mock loop with a regulable blood pump, ECMO oxygenators, a pressure cuff, and an artificial dynamic skin consisting of many layers and blood vessels, see Fig. 4. Thus, the arterial and venous oxygen saturations can be monitored with PPG under in-silico configurable circulatory and skin conditions.

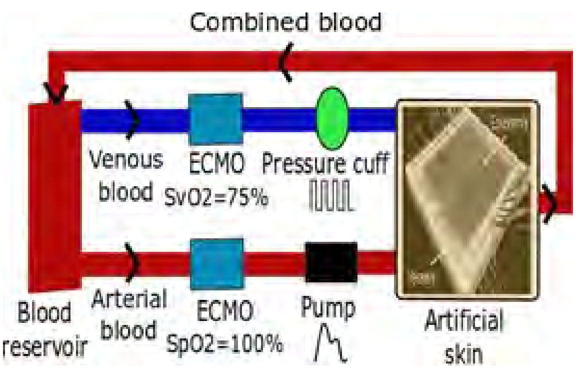


Fig. 4: Blood circulation simulating mock-loop with a regulable blood pump, ECMO oxygenators, and an artificial dynamic skin and blood vessels to monitor oxygen saturation with a PPG sensor under configurable conditions.

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

Automated Phrenic Nerve Stimulation with Mechanical Ventilation

Humans use primarily their diaphragm to breath, but it is not active during traditional mechanical ventilation. This inactivity can lead to ventilator-induced diaphragmatic dysfunctions (VIDD) which is associated with 30 \% of mechanically ventilated patients who are difficult to wean from the mechanical ventilator and to 10 \% who face prolonged weaning. These patient types account for 40 \% of total intensive care unit (ICU) patient-days. To ensure diaphragm activity, the phrenic nerve (nerve of the diaphragm) can be stimulated artificially. Together with Uniklinik RWTH Aachen, this project aims to develop a closed-loop system, which controls the phrenic nerve stimulation and the mechanical ventilation. The closed-loop system has to keep the patient in a safe condition and stimulate the diaphragm adequately to prevent VIDD. An overview of the closed-loop system is shown in Fig. 5. The stimulator generates electrical impulses, which are transmitted through electrodes near the phrenic nerve.

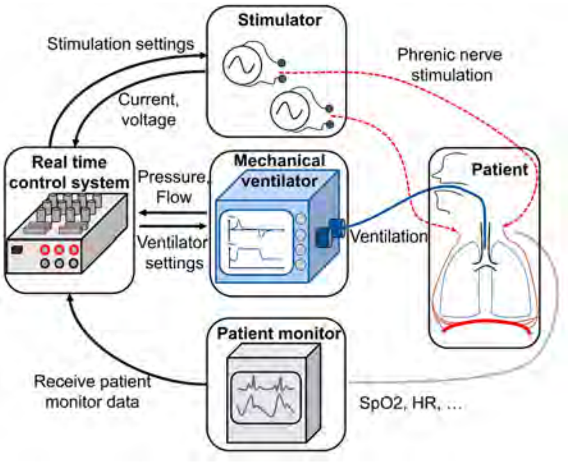


Fig. 5: Overview of the closed-loop system with parallel phrenic nerve stimulation and mechanical ventilation.

These impulses cause the diaphragm to contract, and the patient takes an artificially generated spontaneous breath. The real-time control system receives measurements from the stimulator, the mechanical ventilator and the patient monitor. The stimulator measures the voltage and current during the stimulation impulses; the mechanical ventilator measures the airway pressure and the flow in and out of the lung; the patient monitor measures the patient's condition such as the heart rate (HR) or the peripheral oxygen saturation (SpO2). Based on these measurements, the real-time control system adjusts the settings of the stimulator and the mechanical ventilator.

This critical application imposes challenges on the overall system. The least invasive method to place the electrodes near the phrenic nerve must be found. An error of the stimulation and mechanical ventilation control algorithm could be fatal. An over stimulation may lead to muscle fatigue in the diaphragm. The stimulator and the mechanical ventilator must act coordinated to prevent further damage to the lungs and the diaphragm. To overcome these challenges, several control techniques like robust control, adaptive control or model predictive control are considered.

Funded by: German Research Foundation (DFG)

Hemocompatibility of left ventricular assist devices under pulsatile operating conditions

Heart failure is one of the main causes of mortality in the developed world. Nowadays, heart transplantation is the gold standard therapy for terminal-stage heart failure. However, the number of donor hearts is significantly lower than the existing need. Therefore, heart failure patients are frequently treated by implanting a mechanical left ventricular assist device (LVAD). An LVAD supports the failing heart by pumping an additional amount of blood from the left ventricle to the aorta. Nowadays, most LVADs are rotary blood pumps, which are operated at a constant speed.

One of the most important parameters to assess the hemocompatibility of LVADs is hemolysis. LVAD-induced hemolysis denotes the destruction of red blood cells due to their exposure to the artificial pumping mechanism. Much work has been dedicated in the past to optimize the pump geometry in this respect. Within this research project, we now want to investigate if hemocompatibility can be improved by optimizing the dynamic control of the LVAD.

Fig. 6 depicts a mock circulatory loop according to the ASTM F1841 standard, which can be utilized to assess the hemocompatibility of LVADs. The blood flow within the loop is controlled by the rotational speed of the LVAD and the head pressure by an automatic tube clamp. Typically, porcine blood is circulated for 6 hours within these loops and blood samples are drawn once per hour. The blood samples are then assessed for plasma-free hemoglobin, which is a marker for hemolysis. In the future, these loops will be utilized to assess the hemocompatibility of LVADs under pulsatile operating conditions. At first, we will analyze isolated pump speed pulsatility and subsequently, the loop will be extended to also mimic remaining heart activity.

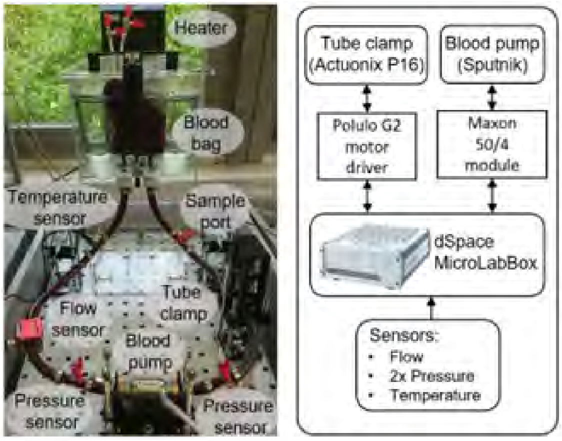


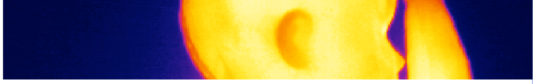
Fig. 6: Mock circulatory loop according to the ASTM F1841 standard equipped with an axial-flow LVAD. The operating conditions (head pressure and pump flow) are automatically controlled using a dSpace MicroLabBox.

Funded by: German Research Foundation (DFG)

Estimation of Force and Torque Development based on Dynamic Muscle Properties

Especially in old age, the decline of muscular units for example due to Sarcopenia results in a significant decrease of independence and thus, life quality. Besides, the constant increase in life expectancy in wealthy countries establishes new challenges for the health case systems. Therefore, non-invasive measuring modalities to assess the muscle's condition and performance are highly demanded for therapy planning.

Recently, a combination of Electrical Impedance Myopgrahy (EIM) and Electromyogram has shown to be promising to assess the muscles geometric, physiological, and metabolic



properties. Nevertheless, both approaches are highly sensitive to the applied electrodes placement. Accordingly, we performed comprehensive Finite Element Method (FEM) modelling analysis to define an optimal electrode placement, focusing on the activity of one specific muscle group, see Fig. 7.

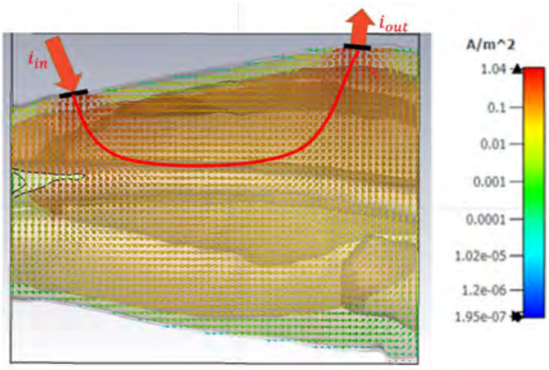


Fig. 7: Simulation of the impact of the applied current feeding on the resulting current density distribution.

Another interesting question is the impact of different kinds of muscle activity on the measured EIM and EMG signal. For instance, a passive lifting assess the state of minimal contraction, contraction without lifting quantifies the muscle's contraction mechanism, and most other daily movements are combinations of both. To enable a delimitation of passive and active forms of muscle contractions, we designed and assembled a passive test-bench for the lower extremities, enabling continuous monitoring of torque, angle, EMG and EIM signals during leg curls, see Fig. 8.

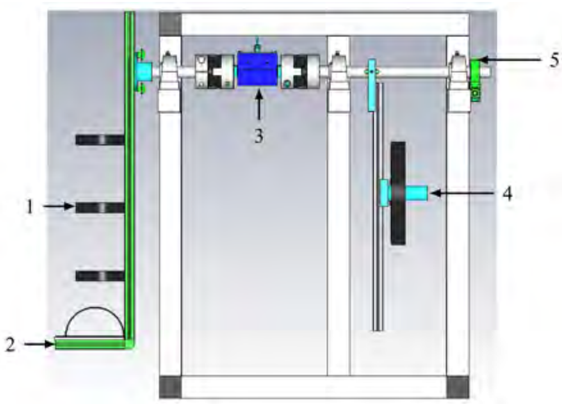


Fig. 8: Schematic of the assembled test-bench, consisting of fixation belts (1), foot-attachment (2), torque sensor (3), counterweight (4) and angle sensor (5).

In combination, the fine-tuning of electrode placement and the performance of guided movements in a limiting environment shall provide deeper insights into the superimposed geometrical and physiological processes, shaping EIM and EMG signals. In the future, their relation to the dynamic process of muscle contraction and relaxation potentially paves the way for new kinds of muscle function tests.

Funded by: German Research Foundation (DFG)

Data fusion for continuous health monitoring of vehicle drivers

Many traffic casualties can be traced back to driver fatigue, drowsiness or other exceptional physiological states such as heart attacks and strokes. Due to the ageing demographics, such physiological problems can be expected to increase. Especially in partly autonomous vehicles, it is crucial to monitor the fitness of a vehicle driver, since the driver must be capable of taking control over the vehicle at any moment. With respect to the elderly, in-vehicle health monitoring also closes the loop of personal health care at home for early detection of diseases.

For personal health care applications, unobtrusive sensing technologies on different modalities are typically used and are embedded into everyday objects, such as driver seats or driver cabins. Such sensors can include capacitive electrocardiography (cECG), ballistocardiography, magnetic induction sensors, radar and camera-based techniques. Due to their unobtrusiveness, these sensors often suffer from a reduced signal quality and motion artifacts.

Apart from developing new, improved sensors, the measured signals must be processed accordingly to extract as much information as possible. For that, data fusion techniques can be employed on three different levels to combine the different sensor modalities, see Fig. 9.

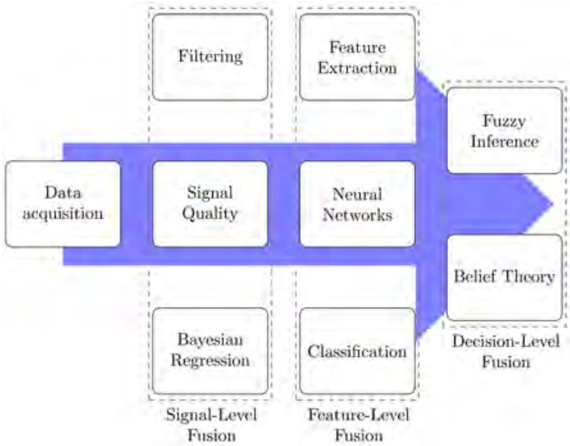


Fig. 9: Process of data fusion with examples for each level.

First, Signal-Level Fusion can be employed on the raw sensor signals to increase the coverage and accuracy of the estimation of vital signs, such as heart rate and breathing rate. Second, Feature-Level Fusion can be applied on previously extracted features such as heart rate, breathing rate or ECG shape to classify the health status of a driver with respect to different diseases. Third, Decision-Level Fusion can be used to decide whether the driver is fit for driving or not, and further measures can automatically be taken into action. These measures can include the coffee cup symbol, often used nowadays to point out drowsiness or fatigue, with the recommendation to take a break. Yet, telemedicinal approaches could also be an appropriate measure in case of a heart attack or a stroke, wherein their detection might be combined with the automatic notification of an ambulance. In the latter case, the car could also automatically drive into a safe location to prevent car accidents.

Medical Information Technology

Selected References in 2022

[1] Selvaraju, V.; Spicher, N.; Wang, J.; Ganapathy, N.; Warnecke, J.M.; Leonhardt, S.; Swaminathan, R.; Deserno, T.M. (2022), "Continuous Monitoring of Vital Signs Using Cameras: A Systematic Review", Sensors, doi: 10.3390/s22114097

[2] Briko, A.; Kapravchuk, V.; Kobelev, A.; Tikhomirov, A.; Hammoud, A.; Al-Harosh, M.; Leonhardt, S.; Ngo, C.; Gulyaev, Y.; Shchukin, S. (2022), "Determination of the Geometric Parameters of Electrode Systems for Electrical Impedance Myography: A Preliminary Study", Sensors, doi: 10.3390/s22010097

[3] Karbing, D. ; Leonhardt, S.; Perchiazzi, G. ; Bates, J. (2022), "What is new in respiratory monitoring?", J Clin Monit Comput, doi: 10.1007/s10877-022-00876-4

[4] Leicht, M.; Walter, M.; Mathissen, M.; Antink, C. H.; Teichmann D.; Leonhardt, S. (2022), „Unobtrusive Measurement of Physiological Features Under Simulated and Real Driving Conditions", IEEE Transactions on Intelligent Transportation Systems, doi: 10.1109/TITS.2022.3143004.

[5] Bergmann, L.; Lück, O.; Voss, D.; Buschermöhle, P.; Liu, L.; Leonhardt, S.; Ngo, C. (2022), „Lower Limb Exoskeleton With Compliant Actuators: Design, Modeling, and Human Torque Estimation", IEEE/ASME Transactions on Mechatronics, doi: 10.1109/TMECH.2022.3206530.

[6] Lyra, S.; Rixen, J. ; Heimann, K.; Karthik, S.; Joseph, J.; Jayaraman, K.; Orlikowsky, T.; Sivaprakasam M.; Leonhardt S.; Hoog Antink C. (2022), „Camera fusion for real-time temperature monitoring of neonates using deep learning", Med Biol Eng Comput, doi: 10.1007/s11517-022-02561-9

[7] Chandrasekaran, S.; Lüken, M.; Leonhardt, S.; Gandhi, U.; Laurentius, T.; Bollheimer, C.; Ngo, C. (2022), „Estimation of Step Length With Wearable Thigh Sensor Using an Unscented Kalman Filter", IEEE Journal of Biomedical and Health Informatics, doi: 10.1109/JBHI.2022.3176432.

[8] Borik, S.; Lyra, S. ; Perlitz, V.; Keller, M.; Leonhardt, S.; Blazek, V. (2022), „On the spatial phase distribution of cutaneous low-frequency perfusion oscillations", Sci Rep, doi: 10.1038/s41598-022-09762-0

[9] Uguz, D. U.; Canbaz, Z. T.; Hoog Antink, C.; Lüken, M.; Leonhardt, S.; „A Novel Sensor Design for Amplitude Modulated Measurement of Capacitive ECG", IEEE Transactions on Instrumentation and Measurement, doi: 10.1109/TIM.2022.3145401.

[10] Linschmann, O.; Leonhardt, S.; Vehkaoja, A.; Hoog Antink, C. (2022), „A. et al. Estimation of the respiratory rate from ballistocardiograms using the Hilbert transform"; BioMed Eng, doi: 10.1186/s12938-022-01024-4

Prizes and Awards

- K. Weike has been awarded the graduation award 2022, by IHK Aachen.
- M. Walter and the team of the PV1000 have been awarded with the Best Paper Award, by VDI Mechatronik.
- The medIT team have been awared with the 2-nd place, during the RWTH FH Sportsday
- During the 26th International Student Conference on Electrical Engineering POSTER, the medIT has been rewarded with the 1-st (P. Borchers), 2-nd (I. Badiola) and 3-rd (F. Röhren) place in the session Biomedical Engineering. Besides, in the session Informatics and Cybernetics the 3-rd (L. Bergmann) and in the session History of Science with the 3-rd place (C. F. Benner).

The MedIT Team