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Automatic crackle detection in children with pneumonia

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Crackles are adventitious, explosive and discontinuous sounds, generally appearing during the inspiratory or also expiratory phase of breathing. Fine crackles are assumed by the sudden reopening of abnormal closed airways, while coarse crackles are assumed by bubbling of air through secretions. The characteristics of crackles are dependent on which lung units in the pulmonary airways are affected – fine crackles with a two cycle duration (2CD) < 10 ms and a high pitch sound mostly occur by a closure of the small airways while low-pitched coarse crackles with longer duration (2CD > 10ms) are found in affected larger airways. Crackles mostly occure in patients with pneumonia, heart failure or asbestosis.

Based on previous work of different research groups we extracted and compared several features and algorithms for crackle detection. The algorithms use especially bandpower- and wavelet-based filters, signal energy and entropy and several more features.

By using Teager-energy and bandpower based filters, as the fastest and most sensitive and specific feature, we developed an own algorithm for detecting crackles in children with pneumonia. Our dataset consists a sample of different night-time LEOSound recordings from the University Hospital of Giessen and Marburg. The sample was rated by a medical expert to compare these results with the automatic detection by our algorithm. We found a high correlation between rater and algorithm.

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A feasibility study to record human knee sounds

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The knee is one of the most complex joint in human body. A misuse or a disease, such as osteoarthritis, can support the mechanical wear of a knee. Besides pain, patients often feel a roughness in the knee joint and hear noises like clicking and rubbing. The analysis of these sounds helps to understand the reasons for pathological sound production and the motion process. This information can utilize to monitor athletes (e.g. football, soccer, and skier) or knee-wearing tasks to develop preventive trainings.

By now there is only one medical device for long-term sound recording, called LEOSound (Heinen + Löwenstein), which is specialized to monitor lung sounds and acoustic symptoms as coughing or wheezing. In this feasibility study we used the LEOSound for knee-sound recording. Two microphones were applied sidewise at the knee joint to minimize artifacts evoked by muscle and cords. In different test-cases (American football practice) the sound recordings show characteristic pattern for clicking and rubbing in a healthy and diseased knees. Our results show that LEOSound can also be used to record knee sounds.

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Major arterial cardiovascular simulator (MACSim) for variational parameter studies in patient-specific vascular geometries

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Cardiovascular diseases are the leading cause of death worldwide. Early detection of abnormal vascular morphologies like stenosis or aneurysms are essential to prevent fatal events. The aim of this study is the development and validation of a patient-specific cardiovascular simulator, that integrates statistical information from measurments of the abnormal pressure-flow conditions to improve the basic understanding and methods in the early diagnosis.

For this purpose, the hardware fluid flow simulator of the systemic circulation MACSim was developed and tested in a series of variational parameter studies. The vascular morphology was generated from a set of MRI images, resulting in a patient-specific artificial one-to-one replica of the human circulatory system. Pulsatile flow conditions were produced by a medical ventricular assist device (VAD) diaphragm pump. The viscosity of the human blood was modelled by a 60/40 vol.-% water-glycerin mixture. Windkessel elements at the peripheral ends of the network allow to vary the pressure and flow conditions within the physiological range.

The considered variational scenario was built upon a nominal arterial stenosis in the left art. femoralis 20 cm upstream the knee. The nominal cross sectional area was reduced between 30 and 80 %, while the length of the stenosis was modified within a range of 5 and 20 mm. Pressure and flow was measured at distinct locations within the system using 20 fluid compatible pressure and four Doppler ultrasound sensors, respectively. The measurement led to a series of multivariate statistical data sets and meta-information about the experiments, which was stored to a MySQL database for futher analysis using extensive data mining and signal classification techniques. The measured pressure and flow waveforms are in good qualitative and quantitative agreement to in-silico simulations and literature in terms of waveshape and specific wave futures like the dicrotic notch, peripheral steeping and translesional pressure drop.

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Respiratory influence on HRV parameters analyzed during controlled respiration, spontaneous respiration and apnoe

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The heart rate variability (HRV) is a measure commonly used to assess sympathetic and parasympathetic autonomic function. It is well known, that respiration can have a strong influence on HRV. Especially, a phenomenon called respiratory sinus arrhythmia (RSA) modulates the RR intervals and is a major contributor to the HRV. The interpretation of common HRV parameters can be ambiguous due to different respiration rates and patterns. To adress this ambiguity, the coupling of RSA on HRV was quantified and HRV parameters were compared during different respiratory states.
A pilot study with five healthy subjects was performed. A three-lead ECG was acquired and the respiration was estimated by measuring the ventilation of the lungs using the PulmoVista 500 by Dräger. This device uses Electrical Impedance Tomography (EIT) to monitor impedance changes due to the changing amount of air within the lungs during respiration. The subjects were asked to breathe at controlled respiration rates of 8, 15 and 24 breaths per minute as well as spontaneously for 1 min each. Furthermore, to analyze HRV during apnoic phases without any respiration, the subjects were asked to hold their breath for 40s at end-inspiration and end-expiration. After preprocessing of the ECG and respiration signal, the coupling between measured respiration and RR intervals was quantified using the Granger causality. If significant coupling was present, the HRV was separated from its respiratory influence using an ARMAX model. The measured respiration hereby formed the exogeneous input to the filter. Common HRV parameters were calculated for the original and decoupled RR intervals. We showed, that coupling strength depends on respiratory rates, which might complicate HRV interpretation. Moreover, the coupling is decreased during spontaneous breathing in comparison to controlled respiration. Additionally, we found, that HRV parameters during apnoic phases differ from decoupled HRV parameters during spontaneous or controlled respiration.

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Beat-to-beat features in peripheral vascular impedance plethysmography for respiratory rate estimation

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With an increasing interest in health, wearable monitors are on the rise. Most devices however are wrist-worn and thus limited in both sensorial and computational complexity. Especially acquiring the respiratory rate comfortably from the limbs has proven difficult, whereby predominantly reflectance PPG-based concepts have been proposed. In some cases, however, even highly integrated, optical measurements are too bulky. Using textile electrodes, for example in socks or gloves, the vascular impedance plethysmography (IPG) can be used to acquire pulsatile signals with minimum obtrusion. We propose a lightweight respiratory rate estimation using time-domain beat-to-beat features from the IPG followed by a spectral feature fusion step. To identify a suitable feature combination, we measured the arm IPG and the respiration in 10 healthy subjects. We then extracted 39 signal frames using automated signal quality assessment. Following, 7 time-domain features have been calculated for each IPG beat: (1) systolic peak amplitude, (2) diastolic peak amplitude, (3) augmentation index, (4) pulse area, (5) pulse interval, (6) crest time, (7) delta-T feature. In order to find the optimal feature combination, an average frequency spectrum over all features for each frame and all 127 possible feature combinations was calculated. The peak in in the physiologically meaningful interval between 6 breaths per minute (bpm) and 36 bpm was used as the respiratory rate estimation. By considering the MSE with respect to the reference rate we were able to select the optimal feature combination [1, 5, 6, 7], which gave the best estimation with an MSE of 1.58 +/- 3.11 bpm over all 39 signal excerpts. An IPG-based respiratory rate estimation in a space-limited environment is therefore feasible. Using only beat-to-beat features in the time domain and the FFT in the fusion step, the proposed concept can be implemented using computationally limited hardware in a wearable device.

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Design and implementation of a teaching system for visual stimulation and recording of single unit and mass signals

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Biosignals can be measured, monitored and analyzed in order to provide information about physiological functions and health statuses. These signals are useful for different types of applications, e.g. evoked potentials (EP). Commercial biosignal data acquisition and logging systems are frequently very expensive, developed via closed-source software and hardware, limited in functionality, difficult to cure defects, difficult to add new features, or not documented in detail. In addition, their level of abstraction is very high or they do not support recent advances in software technologies such as storing the gathered data to the cloud in order to be accessed and used by other systems remotely. We developed a budget priced biosignal data acquisition, logging and visual stimulation system. The system was designed to teach students the in-vivo recording of neuronal signals, e.g. visually evoked potentials or spike activities. The proposed system supports biomedical engineering education by allowing students to measure brain signals data in a flexible and interactive way from anaesthetized flies. Recordings can be done by putting electrodes on the exoskeleton or by positioning fibre micro-electrodes in the vicinity of the optic lobe or central brain. The hardware part of the system consists of supporting mechanical parts, a microelectrode manipulator manufactured according to our plans (by Thomas Recording, Gießen, Germany), National Instruments USB-6211 multifunction I/O device, and a module based equipment (including filter-amplifiers) to record signals and to provide visual stimuli. Here we focus on the stimulation and recording software. The software was written by using the graphical programming language LabVIEW. The recorded data can be stored into MATLAB MAT-files, which assures an easy and open post-processing by the students. Our approach provides the students a bottom up insight into acquisition and processing of electrical neuronal single-unit and mass signals as required for neurosignal and/or neuroprosthetical applications in biomedical engineering.

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Sensor placement in a smart compression shirt to measure spontaneous breathing

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Literature provides various approaches to link upper body surface motion during respiration with the underlying respiratory mechanics. An optimal system would provide a sufficient accuracy, be wearable and able to use in all circumstances - from unconscious patients in bed (to monitor the spontaneous breathing) to competitive athletes during training (to measure the tidal volume during exercise). In conjunction with the development of a smart compression shirt, which is able to assess the tidal volume, this study was done to analyse the required number of sensors in the shirt. Based on optoelectronic plethysmography (OEP), the optimal number of sensors and their positions in the shirt were analysed, regarding their ability to provide a sufficient accuracy for the tidal volume. Therefore, multiple OEP markers were fixed on a compression shirt and the OEP was done within a body plethysmograph, which was used as a reference. The participants wearing the shirt were advised to undertake diverse respiratory manoeuvres. Different algorithms were evaluated to process the obtained data and finally via a spline interpolation in combination with a delauney triangulation the tidal volume was derived from the position of the markers. Subsequently, marker by marker was removed from the dataset and the resulting volume was calculated. The calculation of the tidal volume was still sufficient even when the number of markers was remarkably reduced. The reduction of the quantity of markers / sensors is a compromise, because additional markers improve the accuracy of the measurement while on the other hand they increase the complexity of the measurement system. Dependent on the desired precision for the tidal volume, the optimal number of sensors and their location on the compression shirt was determined. Furthermore, anatomical constraints and the symmetry of the human body can be used to improve the results.

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Consistent mathematical modelling of the perfusion index and the pulse wave velocity measured by combined fingertip photoplethysmography and the electrocardiogram

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The human body has the ability to control the blood pressure in the cardiovascular system by the vasomotor activity of arterial blood vessels. However, these days physicians are unable to reliably monitor these changes in vessel diameter continuously and non-invasivly, nonetheless they could win precious time to react by observing these changes of vessel tone in possibly life-threatenig situations like undetected hemorrage. Therefore, we developed a coherent mathematical model based on physiological and physical principles that links the pulse-wave-velocity (PWV) and the perfusion index (PI) to the unobservable vessel diameter. Conveniently, both PWV and PI can easily be captured by means of routinely employed electrocardiographic and photoplethysmographic patient monitoring systems.
To calculate values for the PWV and the PI the model treats the internal vessel radius and its change as caused by the arterial volume pulse as input parameters, which illustrates the vasomotor activity on the given piece of tube. Furthermore these input parameters are combined through a given law to implement a correlation between them. Consequently, the PI, which is based on the Beer-Lambert law, can experience a noticeable change through vasomotor activity and in the same way the PWV, based on the Moens-Korteweg equation, will also change in value. Both health parameters are subject to different information sources and can be investigated through signalprocessing on fingertip photoplethysmograms and the electrocardiogram. For a simulated change in vessel radius from 0.6 to 1.2 mm as it is related to the radial artery, we calculated pulse-wave-velocities from 565 to 550 cm/s and perfusion index from 9 to 18 %.
As a result it is shown, that the combined mathematical model is able to calculate values for PWV and PI, which are comparable to physiological values recorded on humans.