Magnetocardiography with Optically Pumped Magnetometers Integrated in a Patient Bed

Christin Bald[1], Eric Elzenheimer[1], Julia Kreisel[1], Nico Simoski[1], Alexej Namenas[1], Jens Reermann[1], Thomas Demming[2], Norbert Frey[2], Gerhard Schmidt[1]

Motivation

- **Long term goal:** Better health control due to monitoring at home
- **Short term goal:** Measurement of heart signal in any decubitus position

Concept

- Provide patient bed with several magnetic sensors
- Four commercially available Optically Pumped Magnetometers (OPMs) used [1]
- Selection of best sensor signal
- Heart Rate Variability (HRV) analysis in real-time

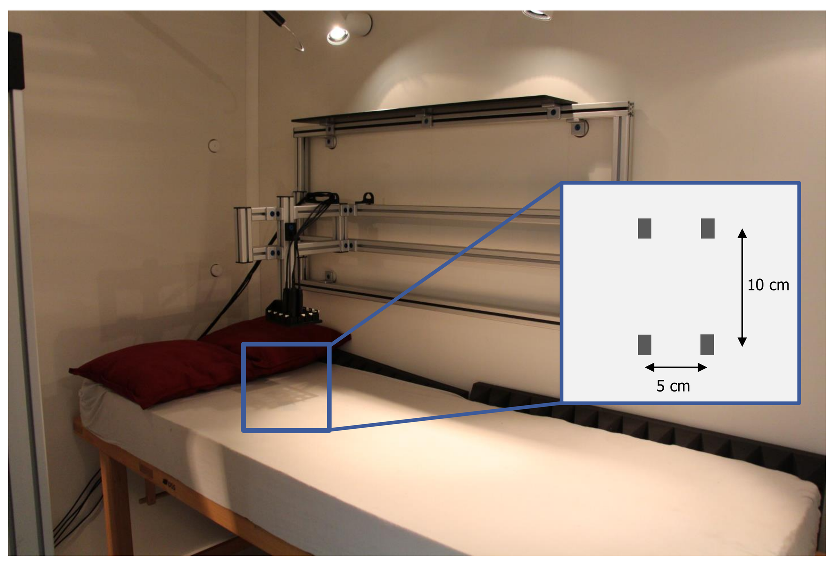

Fig. 1: Patient bed in the shielded chamber equipped with four optically pumped magnetometers.

Preprocessing

- Non-linear and time-variant trend removal [2]
- Low pass filtering with cut-off frequency $f_c = 30\,\mathrm{Hz}$

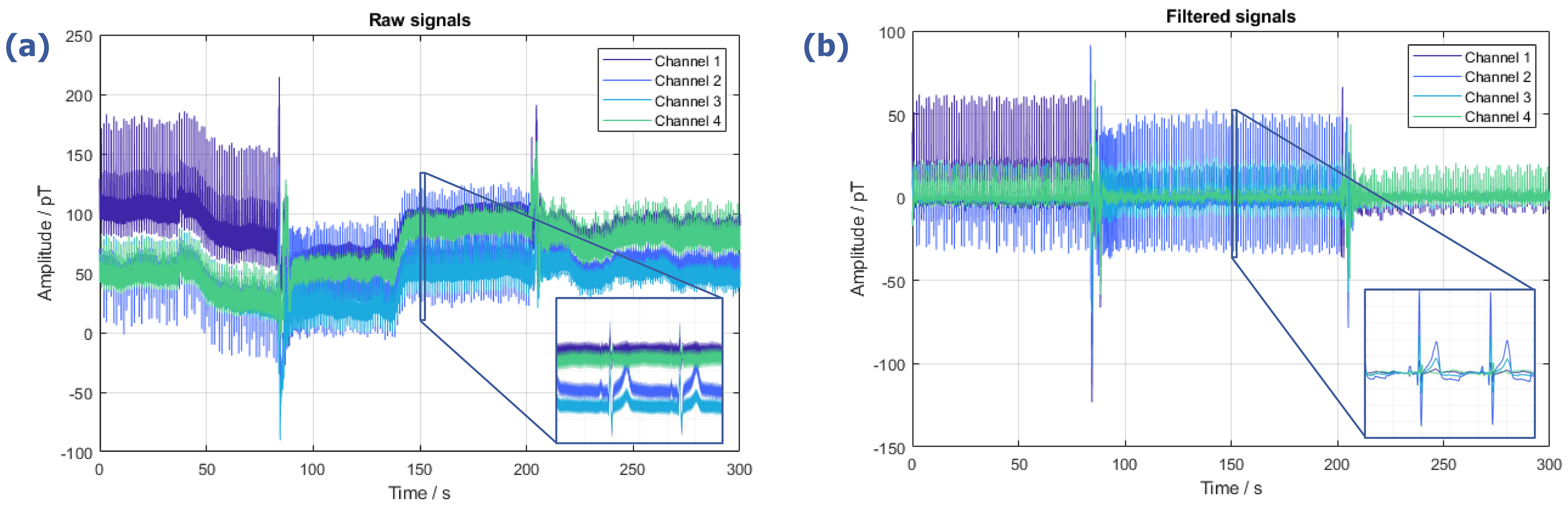

Fig. 3: Signals of the four OPMs (a) before and (b) after preprocessing. The trend of the signals was removed by means of non-linear filtering and the signals were low-pass filtered to remove the noise from the signals. The distortions occurring by turns and movements are still visible and will be removed later.

Sensor selection and removal of turning distortions

- Ensure that heart signal is optimally measured independent of the decubitus position of the patient
- Selection of the "best" sensor signal
  - (Frame-based, index k) calculation of (smoothed) signal variance for every sensor i

$$\sigma_i^2(k) = \alpha\,\sigma_i^2(k-1) + (1-\alpha)\frac{1}{N_f - 1} \cdots$$

$$\cdots \sum_{n=k\,N_f+1}^{(k+1)\,N_f} \left(x_{\mathrm{enh}_i}(n) - m_i\right)^2$$

  - Use sensor with highest signal variance

$$\mathbf{a}(k) = \arg\max\{\sigma_i^2(k)\}$$

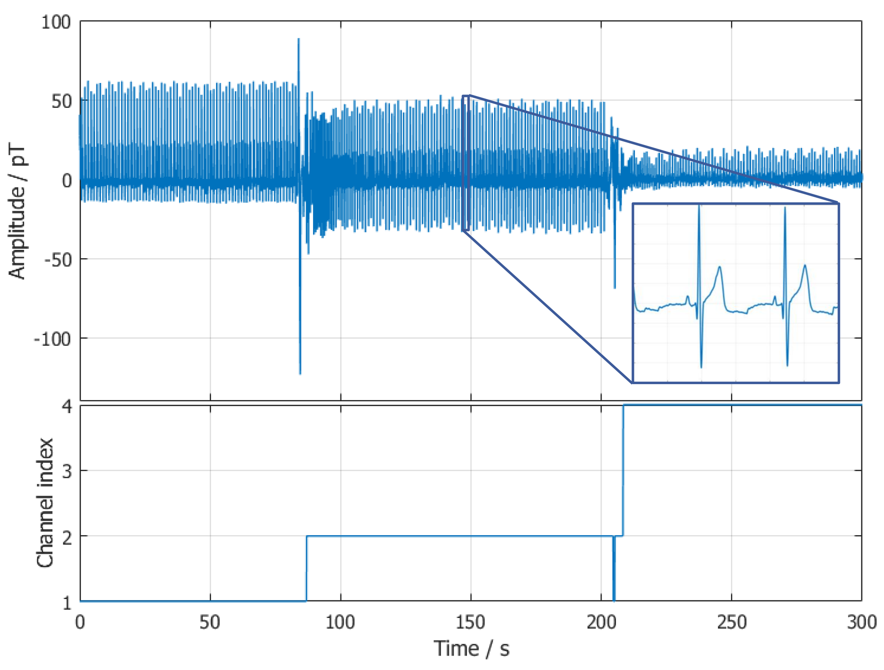

Fig. 4: Selected channel (channel index) and combined signal of the four OPMs. After every change of the decubitus position a different sensor is best for calculating the HRV.

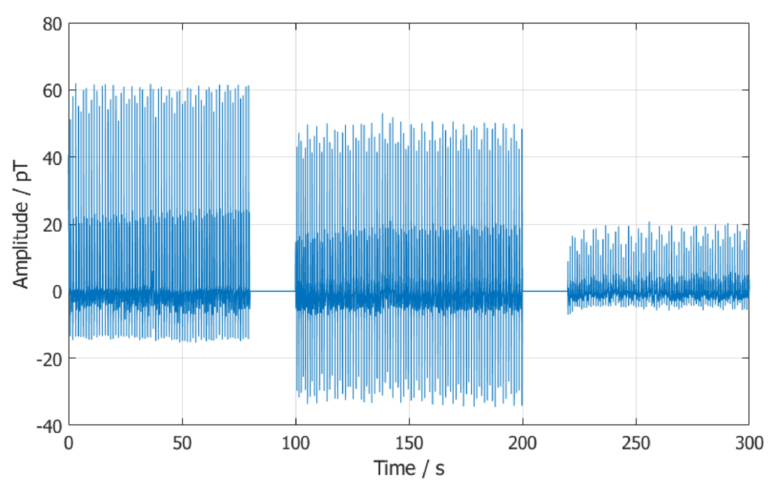

Fig. 5: Combined signal after the removal of the turning distortions. The signal as well as the time index, when the distortions occur, are forwarded to the HRV.

- Turning distortions are set to zero
- ⇨ Peaks are not detected as R waves during HRV
- Time index of distortion segments forwarded to HRV
- ⇨ Prohibit wrong calculation of distances between two R waves (before and after the distortion)

Literature

[1] J. Osborne, J. Orton, O. Alem, V. Shah: Fully integrated, standalone zero field optically pumped magnetometer for biomagnetism. Proc. SPIE 10548, Steep Dispersion Engineering and Opto-Atomic Precision Metrology XI, 105481G (22 February 2018); doi: 10.1117/12.2299197

[2] https://dss.tf.uni-kiel.de/index.php/teaching/red-main/red-trend-removal

System overview

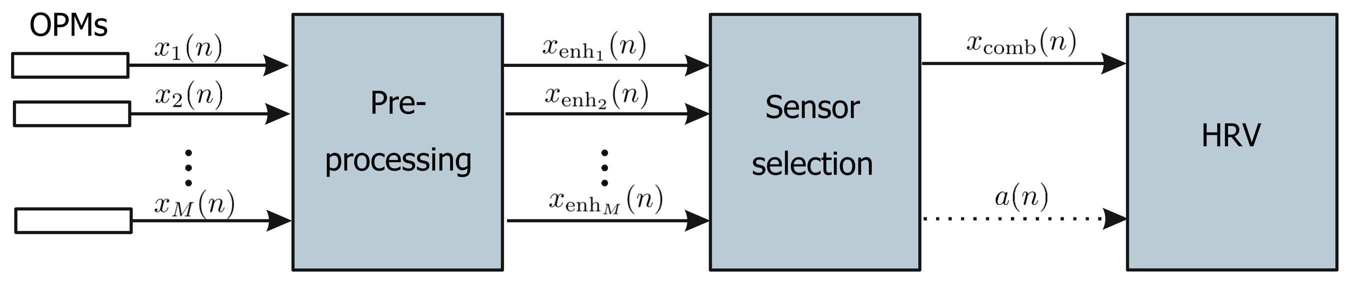

Fig. 2: Overview of the system for enhancement and selection of the magnetic sensor signals for calculation of a heart rate variability analysis.

Heart rate variability analysis

- Comparison of HRV with and without sensor signal selection
- Preprocessing and removal of distortions identical for combined signal and for single sensor signals

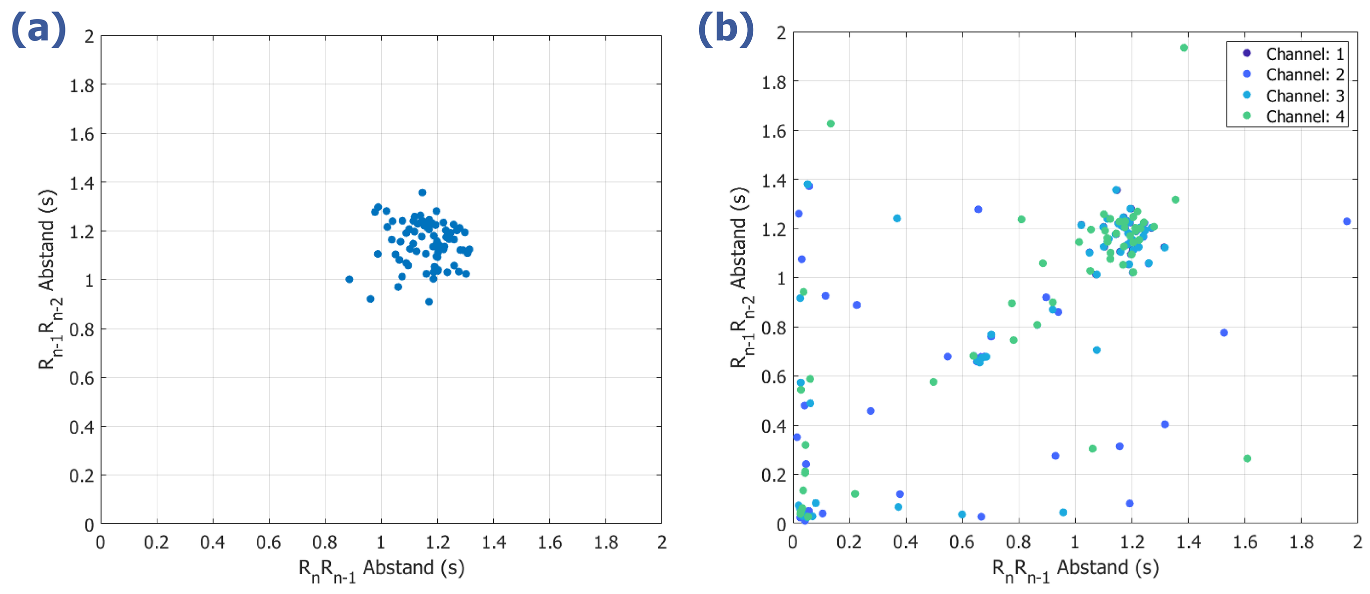

Fig. 6: Comparison of HRV (a) with and (b) without combination of the sensor signals. The HRV without combination is calculated for each sensor individually. The preprocessing steps as well as the removal of turning distortions is done in the same way for the combined signal and for each single signal.

- Computation of HRV in real-time
  - Poincare plot, Tachogram, Histogram, ...
- R-wave detection by edge detection
- Development of a graphical user interface for physicians
- Generation of a report at the end of the measurement

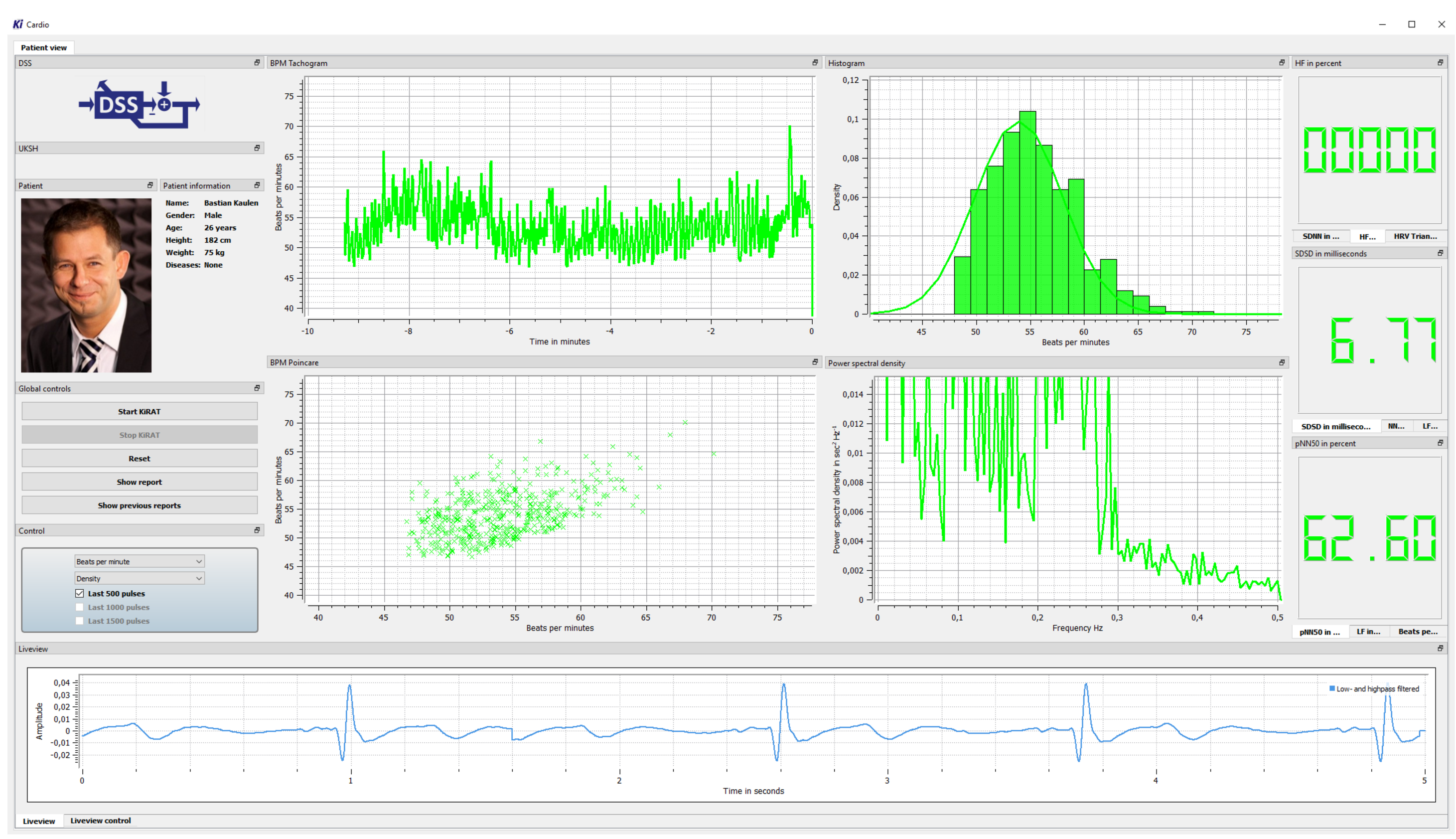

Fig. 7: Graphical user interface of the real-time system for the HRV analysis.

Conclusion and Outlook

- A robust heart rate variability analysis was implemented
- The heart signal could be measured in any decubitus position
- Turning distortions were removed and didn't affect the results of the HRV
- Usage of different magnetic sensors (e.g. magnetoelectric sensors) operating in an unshielded environment
- Equip patient bed with more magnetic sensors in the future

[1] Digital Signal Processing and System Theory, Institute of Electrical and Information Engineering, Kiel University, Kiel, Germany
[2] Department of Cardiology and Angiology, Kiel University, Kiel, Germany

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