Non-contact cardiac gating with ultra-wideband radar sensors for high field MRI

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Cardiac MR (CMR) imaging in a defined phase of the heart cycle requires triggered data acquisition. Systems with B_0 up to 1.5 T utilize ECG signals for triggering. However, due to the increasing perturbing influence of the magneto-hydrodynamic effect on the ECG signal, triggering is additional hampered in high and ultrahigh field MRI systems. The necessity to attach ECG electrodes to the human body is an additional obstacle if patients are unable to cooperate. Therefore, we have developed an alternative, contact-less approach for the detection of cardiac mechanics by means of ultra-wideband

(UWB) radar. The basic idea of UWB sensing is to determine the position and/or displacement of tissue interfaces by measuring the two-way propagation time of the transmitted electromagnetic UWB signal [1]. Due to the different propagation times of signals from different interfaces and different dielectric contrast, the mechanical displacement of a selected interface can be monitored. The raw UWB radar data, however, contain a linear combination of all simultaneously occurring physiological signatures, including the dominating respiratory and cardiac displacements. To extract beneficial information from UWB radar for cardiac MRI the decomposition of respiratory and cardiac displacements is mandatory, since the MRI data have to be unambiguously assigned to the state of the individual respiratory and cardiac cycle. Due to higher harmonics from the highly nonlinear respiratory motion, the extraction of the cardiac motion from the composite signal just by common frequency-domain signal filtering is limited.

Fig. 1: UWB setup in front of the 3T scanner

We applied blind-source separation (BSS) based on several time-delayed second-order correlation matrices to decompose the UWB signals and extract a pure cardiac component. Within this component, we are able to identify landmarks indicating the point of maximal contraction of the myocardium. This article is to present our novel imaging approach, the application of retrospective cardiac triggering based on UWB signals acquired concurrently with a clinical cardio MR sequence.

Materials and Methods

CMR images und UWB signals were acquired simultaneously and synchronously. Two UWB antennas (Rx and Tx) were mounted in frontal position (Fig. 1) inside the bore of the 3 T MR scanner (Magnetom Verio, Siemens, Erlangen). The UWB data were sampled at 44.54 Hz and blind source separation TDSEP [2] was applied to decorrelate the sources of variation in the UWB signal. The cardiac component in the separated sources can be identified automatically by the highest ratio of the maximum spectral power within the basic cardiac frequency range of 0.5 Hz to 7 Hz to the maximum power outside this range. The first minima after the trailing slopes in this signal component were chosen as selected trigger point (Fig. 2: red asterisks). Consistency checks on the oscillation amplitude were used to suppress double triggering. Respiration can be detected by band pass filtering of 0.05-0.5 Hz. To compare our approach with another trigger technique also applicable in high and ultrahigh fields, pulse oximetry (PO) was applied simultaneously with UWB radar. The trigger times identified by pulse oximetry during a clinical MR sequence were replaced by those provided by the UWB radar. From these data, we have retrospectively reconstructed the images.
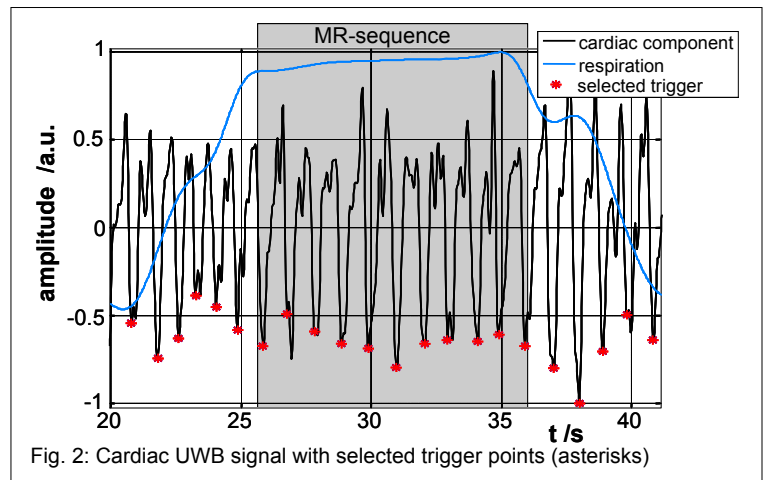

Fig. 2: Cardiac UWB signal with selected trigger points (asterisks)

Results and Discussion

Comparing UWB and PO trigger points we find differences in the range of -46 ms to 101 ms resulting in a standard deviation of 69 ms. In a previous study [3] we compared UWB triggering with high resolution ECG (sampling rate of 8 kHz) and found standard deviations for the time offset between UWB trigger points and R-peaks in the ECG of less than 20 ms. This is already below the UWB sampling time of 22.45 ms. Further studies are needed to understand in detail the increase of the standard deviation

compared to the pulse oximetry, but preliminary analysis points towards an essential jitter in the PO trigger as the major contributor. In summary, we proposed a novel technique to reliably determine trigger points in the cardiac UWB signal. The feasibility of CMR imaging utilizing non-contact UWB radar signals has been demonstrated. There is no significant difference in the reconstructed images of PO and UWB triggered data. An example of reconstructed images by UWB trigger is given in Fig.3. In contrast to established techniques like ECG or PO, the contact-less UWB-sensor provides cardiac and respiratory information simultaneously and thus a sequence-independent external navigator signal.
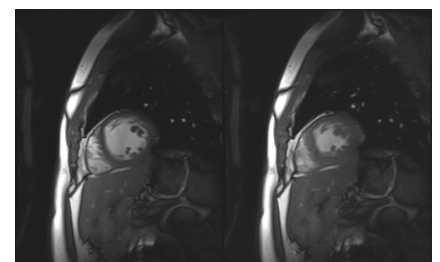
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Fig. 3: UWB triggered reconstructed images

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