Cardiac activity detection with the noise variance of a receive coil

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Purpose: Cardiac activity often results in artifacts in human cardiac MR images, fMRI studies and MR spectroscopy. Currently ECG is the standard sensor in MRI to detect cardiac activity. However, the electric potential measured in the ECG may be altered by the induced electric field in the body generated by the interaction between the blood flow and a strong magnetic field. This magnetohydrodynamic (MHD) effect mainly occurs in the aortic arch, because the blood velocity there is large and roughly orthogonal to the magnetic field. Additionally, the MHD effect increases with higher magnetic field strength [1]. This causes the ECG to become unstable, especially at high magnetic field strength (e.g. 7T).

It has been shown that thermal noise variance of the receive RF coil can effectively pick up the respiratory motion [2]. Here we investigate whether the thermal noise variance is also sensitive to cardiac activity.

Methods: Free breathing experiments on healthy volunteers were performed on 1.5/3/7T MR scanners with 16/32/8 channel arrays. The 16 and 32 channel body receive arrays consisted of overlapping loop coils and, the 8 channel transcieve array consisted of dipole antennas [3]. The arrays were positioned to cover the thorax and, thus the heart. Noise samples were acquired by switching off the RF and gradients during a 2D balanced gradient recalled echo (GRE) sequence (cine MRI frames). Signal was collected with TR=3.1/3.9/2.5 ms, number of collected data samples per TR: 672/688/480 at 1.5/3/7T respectively. For all experiments the time per frame was kept constant at 0.3 s and 120 frames were recorded, so the total acquisition time was 36 s. For every individual coil the measured signal was normalized to its median and band-pass filtered between 0.6-2 Hz (i.e. 36-120 beats per minute). During these measurements the ECG was also recorded to serve as a reference. Power spectra were calculated of both noise variance and ECG signals to compare their dominant frequencies and also their time signal was compared.

Results and discussion:

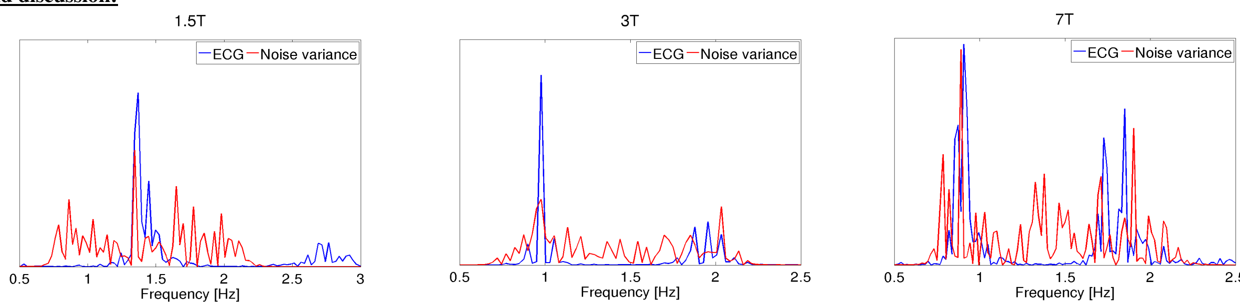

Fig. 1: The normalized power spectra of the ECG (blue) and filtered noise variance (red) of an example coil close to the heart is shown for each field strength. The noise variance was band-pass filtered in the cardiac range 0.6-2 Hz (i.e. 36-120 beats per minute). The dominant frequencies of ECG and noise variance match. Notice the split peak in the 7T ECG measurement, compared to the clear ECG peaks at 1.5 and 3T.

All measurements show the clearest cardiac activity in coils which were in close proximity to the heart. The dominant frequency of cardiac activity could easily be distinguished in the power spectrum of the noise variance fluctuations of at least one of the coils close to the heart for all field strengths. The power spectrum of one such a coil per field strength is shown in Fig. 1. Notice the normalized power of the dominant frequency of the noise variance compared to the ECG is lower at 3T than at the other field strengths. The respiratory component (outside of the cardiac frequency range shown in the graph) that is orders of magnitude larger than the cardiac activity present in the measured noise variance of this particular coil suppresses the components in the cardiac frequency range. The same frequency was dominant in the power spectrum of the ECG signal. The power spectrum of the noise variance has more sidebands compared to the ECG, but this can be solved by using an adequate filter instead of just a band-pass filter between 0.6-2 Hz. To show this, a narrower band-pass filter was applied around the cardiac frequency to the same coils shown in Fig. 1. The resulting power spectrum and temporal modulation of this narrower filtered noise variance are shown in Fig. 2. The filter widths were 1.2-1.5/0.8-1/0.8-1 Hz for 1.5/3/7T respectively. The amplitude variation over the observation time of the noise variance fluctuations is most likely caused by the used band-pass filter or the remaining side bands. The temporal modulation of the ECG and noise variance fluctuations match in frequency. In the time domain there is a different time shift between the peak of the noise variance and ECG for the different field strengths. This can be explained by the fundamental differences between the physical processes that underlie the noise and ECG measurements. The ECG measures electric activation of the heart directly, whereas noise arises from the entire body volume, spatially weighted by the coils RF electric fields. This means that noise variance consists of a complex convolution of cardiac and anatomical activity (e.g. breathing, aorta pulsation, atrial and ventricular contraction).As a result, it is possible to detect the dominant cardiac frequency with each of the three shown coils, but due to their different locations with respect to the body and operating wavelengths the temporal signals are shifted.

To improve sensitivity of the noise variance to the cardiac activity, principal component analysis (PCA) of multiple coils close to the heart will be investigated in the future.

Conclusion: The cardiac activity is present in the noise variance fluctuations at multiple field strengths (i.e. 1.5, 3 and 7T). The proposed method doesn't require additional hardware (e.g. ECG electrodes and wires). An application of this technique could be retrospectively sorting of dynamic cardiac data (e.g. read out lines) in case ECG triggering was not available or problematic. For real time triggering the signal processing has to adapted as the applied band-pass filters lead to phase lag. In that case Kalman filtering of noise data could be an alternative.

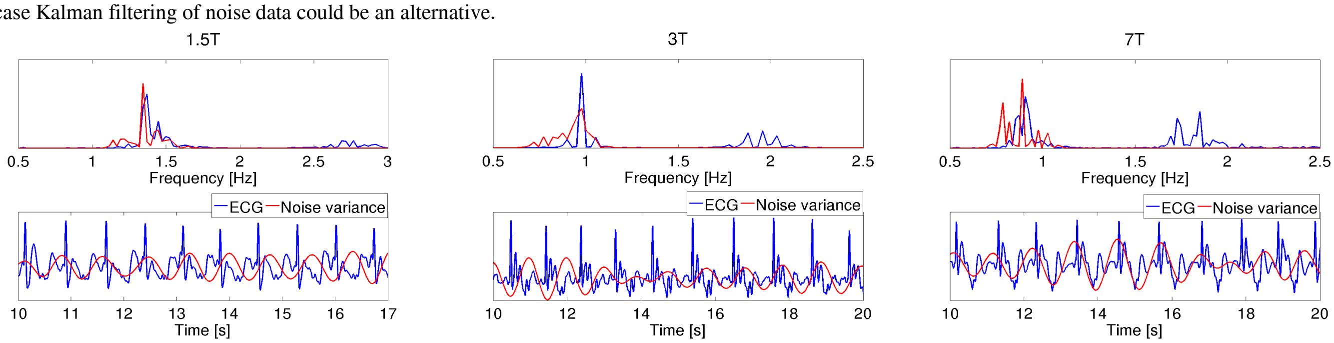

Fig. 2: The power spectrum and temporal modulation of the ECG (blue) and filtered noise variance (red) of an example coil close to the heart for each field strength. Each noise variance signal was band-pass filtered around the specific cardiac frequency of the volunteer and only 10 heart beats were shown to improve visibility. Notice that the temporal modulation of the noise variance matches the ECG.

References: [1] Martin V, et al. (2012) Phys Med Biol 57:3177; [2] Andreychenko A, et al. (2013) ISMRM 21:92; [3] Raaijmakers A, et al. (2014) ISMRM 22:314.