Optimal Channel Selection for Respiratory Self-Gating Signals

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INTRODUCTION: Motion due to respiration poses a significant challenge for MR imaging of the abdomen and thorax. However, it is possible to compensate for the motion, e.g. by accepting data from only a certain respiration phase, when the temporal phases during the acquisition are known. Traditionally, the respiration phases are obtained using respiration bellows, but the clinical acceptance of such devices is very low. Self-gating techniques determine this information directly from the measurement data, in contrast to navigator techniques that perform additional intermediate navigation scans. Because the navigation scans interrupt the steady state of the magnetization and because navigators prolong the overall scan time, self-gating is favorable for T1-weighted gradient-echo (GRE) sequences[1,2]. Radial k-space trajectories are particularly well suited because they continuously sample the center of k-space, which allows for detection of respiratory motion. Several algorithms have been proposed for the signal extraction[1,2,3,4] where in most methods a suitable coil element has to be selected manually to get reasonable results. This is time-consuming for modern MRI systems with high number of receive channels, and infeasible for clinical routine applications. Here, we propose a fully automated procedure to generate proper self-gating signals for 3D stack-of-stars GRE sequences with golden-angle sampling[5], which are comparable to the signal from a respiratory bellows.

MATERIALS AND METHODS: The self-gating signal is computed in two algorithmic stages: First, extraction and filtering of separate one-dimensional signals for every acquired channel and, second, selection of one channel with the most suitable signal.

In the first stage, self-gating signals are calculated from the central k-space partition ($k_z = 0$) of every channel. Instead of using only the peak-echo magnitude of every radial readout[2], the sum of magnitudes over the 5 central k-space samples is used, which proved to be more stable. Angular-dependent fluctuations in the 1D signal are then reduced by applying a Gaussian filter (σ = 1/16 of the total number or readouts) to the samples after sorting the data according to the acquisition angle[6]. Finally, temporal smoothing is performed by applying a Gaussian filter (σ = 0.5 s) to the signals.

In the second stage, the signal that is most representative for the respiratory motion has to be selected from the set of channels. All signals are first Fourier transformed and normalized with respect to their energy because the signal energy should not bias the signal selection. Afterwards, a Gaussian lowpass filter (σ = 0.05 Hz) is applied to smoothen the spectrum. A quality measure θ for the respiration signals is then computed with $\theta_i = R_i / H_i$, where R_i denotes the local maximum in the range of typical respiration frequencies (1/12 – 1 Hz) and H_i denotes the energy of the high-frequency spectral components (> 1 Hz) for receive channel *i*. This measure favors smooth signals with a pronounced peak in the range of reasonable respiration frequencies and with low contributions at higher frequencies, e.g. due to cardiac motion. The highest ratio between the respiration-peak amplitude and high-frequency energy indicates the most reliable respiration signal across all receive coil elements.

The described procedure was performed on 16 datasets from four volunteers acquired with varying scan protocols, including at least one coronal and one transversal acquisition for each subject. All scans were conducted at 3T with a Siemens MAGNETOM Skyra MR system (Siemens AG, Healthcare Sector, Erlangen, Germany) using an 18-channel body coil and a 32-channel spine coil (24.5 elements enabled on average). To validate the calculated self-gating signal, the sequence was modified to record the signal from a respiration bellows synchronously with the raw data. For every acquisition, the average score across all channels θ_{avg}, the maximum channel score $\theta_{\max}$, and the score for the bellows signal θ_{ref} were computed.

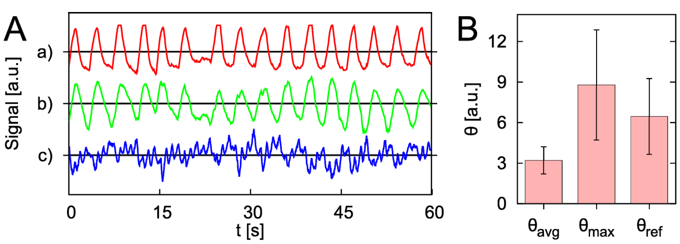

Figure 1A: a) Reference signal from respiration bellows, b) self-gating signal from channel with highest rating, and c) from channel with lowest rating according to the proposed measure.

Figure 1B: Mean average score of all channels, mean score of optimal channel for the self-gating signal, and mean bellows signal score. Error bars indicate one standard deviation.

RESULTS: For all datasets, the automatic channel selection delivered a visually plausible respiration signal. Fig. 1A shows the recorded bellows signal in comparison to the self-gating signal from the channel with b) highest and c) lowest score for one exemplary dataset. It can be seen that the lowest-rated signal shows strong fluctuations that are uncorrelated to the respiration detected by the bellows sensor, while the best-rated signal is consistent with the sensor signal. On average over all datasets, the self-gating score averaged across all channels was 3.20+/-1.01 while the score for the best signal was 8.78+/-4.08 and the score for the reference bellows signal was 6.45+/-2.81 (see Fig. 1B). The bellows signal score was particularly low in cases where amplitude cut-offs occurred due to the limited sensitivity range of the sensor, which significantly affected the reliability of the bellows signal.

To demonstrate the feasibility of using the estimated self-gating signals to compensate for respiratory motion, Fig. 2 shows reconstructions where the signal amplitude was used to partition the acquired data into three equally sized bins (exhaled, intermediate, and inhaled) in comparison to a reconstruction using all data. The motion blur present in the non-gated image was significantly reduced.

CONCLUSION: This work describes a fully automated procedure to generate respiratory self-gating signals from free-breathing acquisitions with a 3D golden-angle stack-of-stars sequence. It includes signal extraction, filtering, and selection of the most suitable receive channel by taking the expected curve shape into consideration. This eliminates the need for manual interaction and enables routine use of self-gated 3D GRE acquisitions.

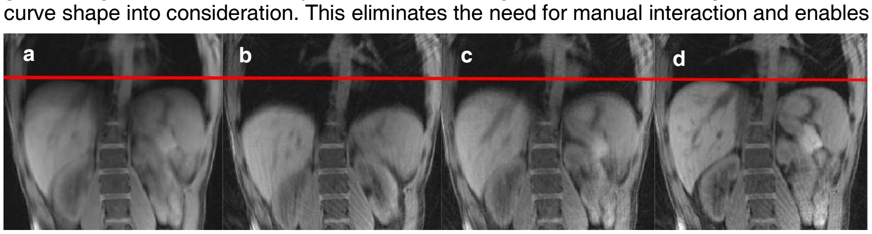

Figure 2: a) Ungated free-breathing acquisition with coronal slice orientation; b-d) Retrospectively gated reconstructions at inhaled, intermediate and exhaled states.

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