Simple Self-Gating for Compensation of Respiratory Motion using a Spiral k-Space Trajectory

R. L. O'Halloran[1], M. Aksoy[1], T. Kober[2], and R. Bammer[1]
[1]Department of Radiology, Stanford University, Stanford, CA, United States, [2]Laboratory for functional and metabolic imaging, Ecole Polytechnique Fédérale de Lausanne, Lausanne, Switzerland

Introduction: External respiratory monitoring is required for most MRI exams of the body and is typically achieved either through the use of a respiratory belt, which wraps around the torso and measures displacement of the chest/abdomen, or an 1D/2D navigator measurement. Whilst belts take some time to setup, can drift, and are on occasion not reliable enough (e.g. children or uncooperative patients), navigators can interfere with certain pulse sequences (e.g. balanced SSFP). An alternative approach is to look at the MR signal itself; specifically, how it can be modulated by respiration or other physiologic properties such as cardiac pulsation. For example, in fMRI it has been reported that subtle susceptibility differences, induced by different amounts of air in the lung can affect signal stability [1-2]. Probably, of greater relevance for body imaging is the effect of coil sensitivity fluctuations due to a varying distance between receiver coil elements and the body, and even more so due to differences in coil loading of the coil over the respiration cycle. The latter is seen as a change in S_{11} (i.e. reflection coefficient) and influences both B_1^+ (e.g. altered tip angle) [3] and B_1^-. Recently, it has been shown that also head motion influences the coil signal and can picked up and corrected by FID-navigators [4]. Indeed, FIDs occur almost in every sequence as result from slice-selective excitation or refocusing. Often they are unwanted signals one attempts to spoil away. In this work, however, we will 1) investigate whether or not physiological signals can be detected from FIDs of individual coils; and if possible 2) leverage on these signals to perform motion-correction on abdominal scans.

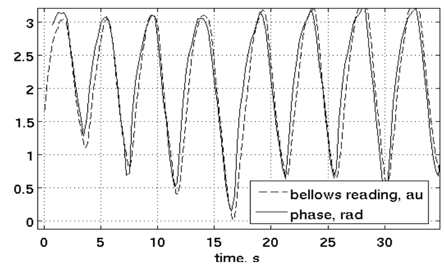

Fig 1: The phase of the DC signal in one of the 8 coils versus time (solid line) compared to the reading of the respiratory bellows versus time (dashed line). The two curves are in very good agreement. Note that the units on the y-axis for the phase are radians while the units for the bellows reading are arbitrary.

Methods: • *Data acquisition* – MRI data were obtained from one human volunteer using a 2D constant-density spiral-trajectory GRE sequence on a 1.5T GE scanner (GE Healthcare, Milwaukee, USA). Signal reception was performed with an 8-channel body array with 22 spiral interleafs, TE/TR = 20/250 ms, 125 kHz Bandwidth, 48 cm FOV, and 1.5 cm slice thickness. Simultaneously, standard physiological recordings were performed. Gradient delays on each axis were measured using the method of Robison and Pipe [5] and corrected for in reconstruction by delaying the ideal waveforms. For the first experiment the subject was asked to breathe normally during the scan. For the second experiment several breath-holds were taken during the scan to assess the drift of the respiratory belt and the TR was decreased to 125 ms to better sample the cardiac signal.

• *Physio data retrieval* – The signal from one coil was used with the coil selected that had the largest variation in phase over the exam. This signal is available at least n_{slice}-times within one TR. Typically, the first couple of time points of a FID suffice so that the extra time for the FID measurements is negligible. In fact, in our application, the DC point of the spiral readout was used. The time course of phase signal of the coil was unwrapped using MATLAB. Respiratory bellow signal was scaled to have the same maximum and minimum value as the phase of the coil for comparison.

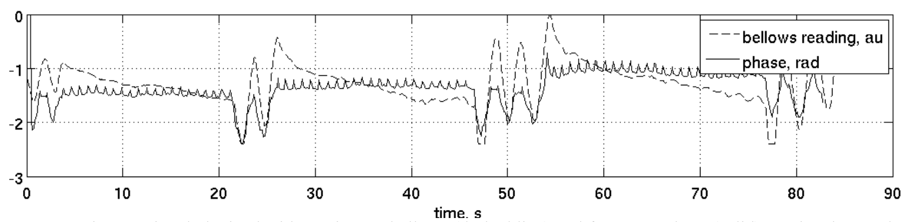

Fig. 2: Respiratory signal obtained with respiratory bellows (dashed line) and from FID phase (solid). Notice the regular heartbeat signal during the long breath-hold intervals. Clearly, the adaptive mechanism of the bellows lets the respiration signal drift during the long breath-hold cycles.

• *Image reconstruction* — Reconstruction was performed using gridding and Voronoi density-compensation as well as the aforementioned corrections for gradient delays. Reconstruction of the first free-breathing experiment was performed by retrospective gating. Here, both the bellows signal and the FID-based self-gating method was used for comparison. Depending on the respiratory excursions interleaves were placed into different bins. For both methods, interleaves were included in reconstruction that had signal in the top twenty percent bin. An un-gated reconstruction was done for comparison.

Results and Discussion: The excellent agreement between the phase of the first points of the FID and the bellows signal is demonstrated in the free breathing example (Fig. 1). In fact, even the heartbeat of the volunteer could be well obtained and is seen best during the breath-hold intervals (Fig. 2). The un-gated image (Fig 3a) is compared to the gated images for both methods. The obvious improvement in image quality of the gated methods over the un-gated one is apparent, however there are no significant differences observed between the self-gated (Fig 3b) and the bellows-gated (Fig 3c) images. This implies that abdominal imaging may be done without the use of a respiratory bellows for gating. The present approach shows surprisingly well physiological signal. It is simple and requires only minor additions to existing pulse sequences. As presented here, it is a retrospective gating technique and therefore shares drawbacks of such methods, such as increase in scan time and the potential to under-sample certain regions of k-space. However, the technique is compatible with recently presented prospective self-gating methods [5] in which a separate FID signal is read in real time and used for gating. Additional measures such as Kalman filtering [6] may be useful to make the technique more robust to drift and patient motion as well as to take advantage of signal from all coils.

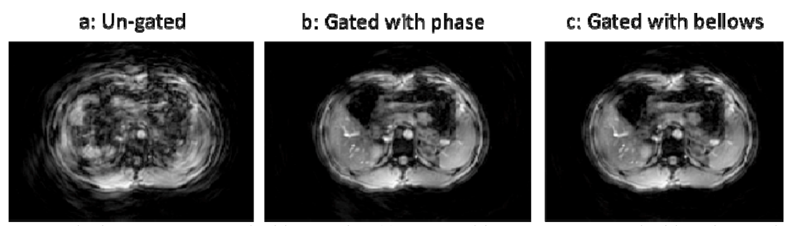

Fig. 3: The image reconstructed without gating (a) compared images reconstructed with gating on the phase of the DC signal (b) and with the bellows (c). No significant differences are apparent between images gated with phase (b) and with the bellows reading (c).

Conclusion: Preliminary results for a self-gating method for spiral imaging of the abdomen were presented. The self-gating signal was shown to be in good agreement with the external bellows signal and no significant differences were observed between images reconstructed with both methods. Future work will focus on abdominal imaging in children where external respiratory gating can be unreliable and patient cooperation is sometimes limited.

References: [1] Pfeuffer J et al. MRM 2002; [2] van Gelderen P et al. MRM 2007; [3] Graesslin I et al. ISMRM 2007; [4] Kober T et al. ESMRMB 2009; [5] Robison RK and Pipe JG. ISMRM 2009; 569. [5] Curcic J et al. ISMRM 2008 ; 203. [6] Spincemaille et al. MRM 2008.
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