A correlation based approach to respiratory self navigation for multi channel non-Cartesian MRI

Gregory R. Lee[1,2], Yong Chen[3], and Vikas Gulani[3,4]
[1]Radiology, Cincinnati Children's Hospital Medical Center, Cincinnati, OH, United States, [2]University of Cincinnati, Cincinnati, OH, United States, [3]Radiology, University Hospitals Case Medical Center, Cleveland, OH, United States, [4]Radiolgoy, Case Western Reserve University, Cleveland, OH, United States

Target Audience: Physicists and clinicians interested in self-navigated 3D non-Cartesian imaging.

Purpose

3D non-Cartesian imaging is highly promising for application to free-breathing abdominal MRI [1-6]. To deal with respiratory motion, data is often divided into a set of respiratory bins. One bin is chosen as a reference and a nonlinear warp of the other respiratory bins to the reference is performed. Warps corresponding to each motion bin can be stored and then reused during the reconstruction of individual frames of the timeseries [3-5]. In this work we evaluate a method for respiratory self-navigation from multi-coil non-Cartesian acquisitions that repeatedly sample the center of k-space. In a previous publication, respiratory position was derived from a series of images that were reconstructed at full resolution (1.8 mm) along the primary motion direction (S/I), but substantially reduced resolution (~1 cm) in the orthogonal dimensions to allow reconstruction at only 0.5 s/frame. While this approach was shown to be feasible it is extremely time consuming and the choice of the “pencil-beam” location within the reconstructed volume was not fully automated. In the present work, we consider an approach using only the central k-space samples, so that no image reconstruction is needed. It has been previously reported that the magnitude or phase of this central point can be used to track respiration [e.g. 7]. In the case of a multi-coil acquisition, it is necessary to either choose an optimal coil or combine signals from the coils in some manner. In this work we chose to use a correlation based approach similar to that proposed by Hu et. al. [8]. That work involved concatenating repeatedly acquired Cartesian central k-space lines, while in the present work we use just the central k-space point at the start of each non-Cartesian readout.

Methods

Six human subjects were scanned with informed written consent in accordance with local IRB and HIPAA protocols. Images were acquired with a multi-echo 3D radial flash pulse sequence (TR=8.4 ms, resolution = 1.8 mm isotropic, FOV=380 mm, 9 radial lines per shot). 4096 unique shots were repeated 8 times (total imaging time: 4 min 36 s). For five of the subjects, injection of contrast (Gadobenate Dimeglumine, single dose) was performed at approximately 70 s into the scan. For the remaining subject, no contrast was administered and the breathing pattern was purposely alternated between normal breathing, breath-hold and hyperventilation. Signal reception used a combination of 6 flexible torso array elements and either 6 or 9 spinal array elements, depending on subject size. Respiratory waveforms were acquired via a respiratory bellows for three of the subjects.

The proposed approach begins by extracting complex-valued timecourses corresponding to the central k-space point for each coil. A consideration unique to the present work is the bulk shift in both the phase and magnitude of the central k-space signal that accompanies the arrival of the contrast agent (Fig. 1, top). These gradual changes in contrast were removed by highpass filtering with a Gaussian kernel at a cutoff frequency of 0.2 Hz. Lowpass filtering at a frequency of 2.0 Hz was also applied to remove high frequency noise situated well above the expected frequency range of respiration (4 Hz was used instead for the subject with deliberate hyperventilation). A matrix of size [N_{time} x N_{coils}] containing the filtered timeseries was formed. Rather than choose an explicit reference timepoint, a full correlation coefficient matrix of size [N_{time} x N_{time}] was computed. The top 10% of the rows showing the highest average correlation across timeframes were then selected. The average of the correlation coefficient matrix for this subset of rows was then used as self-navigation waveform. This differs from the approach of Hu et. al. in that no explicit reference time-frame is chosen.

Results and Discussion

Fig. 1, top shows the raw signal for a single channel in a representative subject. The bulk signal shift starting around 80 s is due to contrast arrival, but the superimposed respiratory variations are still clearly visible. The bottom panel shows the same signal after bandpass filtering. For this single channel there is substantial noise still present in the timecourse. Fig. 2 shows the self-navigation waveform as determined via the proposed correlation approach, showing good agreement with the respiratory bellows. In Fig. 3, the case of deliberately irregular respiratory waveform was also examined, demonstrating significant disagreement with the respiratory bellows. This is partly due to clipping of the bellows signal, but substantial differences during the central breath hold are also present. For this case, the approach of image-reconstruction followed by motion estimation in the image domain was performed for reference. The image-domain navigator agrees well with the correlation-based self-navigatior.

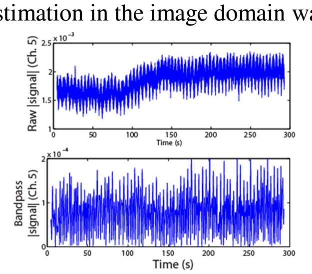

Fig. 1. Raw and bandpass filtered signal from a single channel.

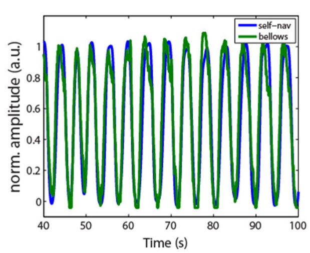

Fig. 2. Zoomed view of the final self-navigated waveform (blue) and the respiratory bellows signal (green).

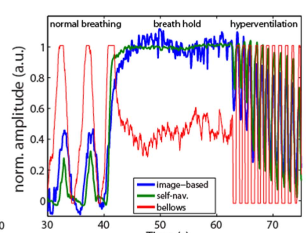

Fig. 3. Irregular breathing pattern example. The bellows (red) shows significant clipping and is in poor agreement with the other two methods during the breath-hold period.

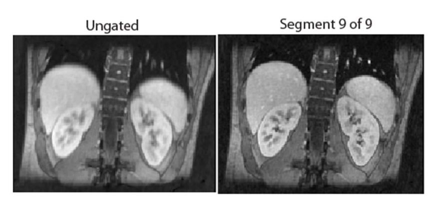

Fig. 4. Ungated timeseries average (left) vs. retrospectively binned segment 9 of 9 (right). Self-navigation effectively reduces image blur.

Conclusions The proposed correlation-based self-navigation approach was determined to provide a good estimate of respiratory motion with only a minimum amount of computation (a few seconds). This will be of use in retrospective binning of dynamic non-Cartesian MRI, particularly in cases such as neonatal or pediatric MRI where the respiratory bellows signal is often less reliable.

References: 1. Buerger et. al. Magn Reson Mater Phy 2013, p. 419; 2. Chandarana et. al. Investigative Radiology 2013, p. 10; 3. Grimm et. al. Medical Image Analysis 2015, p.110; 4. Bhat et. al. Magn Reson Med 2011, p.1269; 5. Lee et. al. Proc ISMRM 2013, p. 3752; 6. Chen et. al. Proc ISMRM 2013, p. 601. 7. Larson et. al. Magn Reson Med 2004, p. 93; 8. Hu et al. Magn Reson Med 2011, p. 467

Support: This work was supported by NIH grant 1R01DK098503-01A1