A Robust and Automatic Cardiac and Respiratory Motion Detection Framework for Self-Navigated Radial MRI

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Target Audience: Scientists and researchers who have interest in self-navigation, cardiac and respiratory motion detection/correction in cardiac MRI

Introduction: External ECG triggering/gating is a valuable tool for synchronizing cardiac cycles in clinical cardiac MRI [1]. However, the ECG signal quality may be affected by interference from gradient switching, and at 7 Tesla or even 3 Tesla, its use is limited due to magnetohydrodynamic effects [2]. Moreover, arrhythmias impose additional challenges and the setup of the ECG prolongs examination time. Self-navigation is an attractive alternative to cardiac cycle synchronization, particularly at 7 Tesla. Self-navigation has been widely used in radial imaging [3] due to the unique property that each spoke goes through the center of k-space and provides an inherent navigator signal given by the average signal intensity over the entire image for each time point. Free-breathing cardiac cine imaging would be significantly improved if both cardiac and respiratory motion can be robustly detected [4]. However, these two types of motion are usually superimposed in the navigator signal and high intensity fat signals from the chest wall or the back further challenge the separation of cardiac and respiratory motion. Multiple receive coils help to differentiate these two types of motion and furthermore, different band-pass filters with specific frequency ranges can be applied for separation of cardiac and respiratory motion [4]. However, although this method works well on volunteers [4], it might not be robust in patients with different kinds of arrhythmias, where the length of cardiac cycles is differing and thus the band-pass filter may fail to capture the cardiac contraction with different patterns and shift the end-systolic/diastolic positions, resulting in motion blurring. The performance of the filter is also degraded in the presence of very irregular breathing. In this work, we propose a new approach for robust and automatic cardiac/respiratory motion detection from multicoil radial k-space and demonstrate its performance on both volunteer and patient in free-breathing scans.

Methods: In cardiac MRI, the region of interest (ROI), e.g. myocardial wall, is usually located within a small region. The conventional self-navigation technique for radial MRI uses the full FOV, which includes unwanted signals and consequently and thus reduces the capability to accurately detect the motion signal. Improved cardiac motion detection can be obtained if the area to compute the navigator signal is restricted to the ROI. In this work, we restrict the area using cropped image projections. According to the Fourier-slice theorem, the projection of the entire image along a given angle is the 1D Fourier transform (1D-FT) of the radial k-space line at that angle. Our method restricts the area by cropping the projection to the ROI (Fig. 1). A new radial k-space line that corresponds to the ROI only is generated by inverse 1D inverse FT of the cropped projection. In order to automate the process, the process mentioned above is repeated for ROIs with different sizes and multiple coils. The signals with the highest frequency peak centered at the cardiac motion range (e.g. 0.6-2.6 Hz) and respiratory motion range (e.g. 0.1-0.6 Hz) are selected as cardiac and respiratory navigators respectively.

The proposed motion detection approach was tested on one healthy volunteer (male, age=27) and one patient with arrhythmia (female, age=45) on a 1.5T MRI scanner (Avanto, Siemens) equipped with a 12-element receive coil array. A 2D b-SSFP sequence with golden-angle radial sampling was implemented for data acquisition with HIPAA-compliant and IRB-approved. A total of 5500 radial spokes were acquired in 15 seconds at a middle short-axis plane. The proposed approach was applied for both cardiac and respiratory motion detection in MATLAB (MathWorks, MA). For comparison purposes, the band-pass filtering approach proposed in [4] was also performed in the patient data.

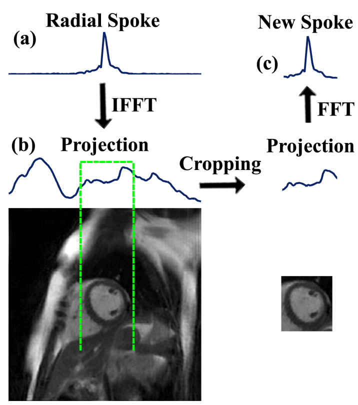

Fig. 1: Motion detection pre-processing. First, radial k-space lines are transformed to image projections using the Fourier-slice theorem. Second, the projection is cropped to the ROI (green lines). Third, a new radial k-space line is generated by transforming the cropped projection back to k-space.

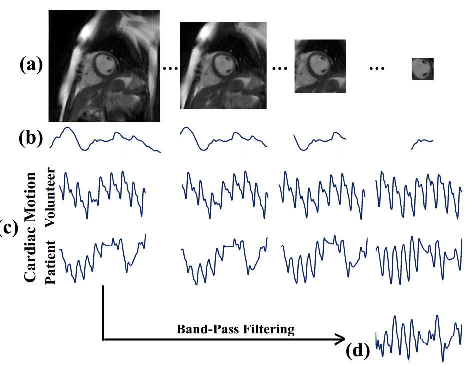

Fig. 2: Automatic motion detection process. (a) Different ROIs used to crop the image projections. (b) Corresponding cropped projections (c) Cardiac motion signals extracted from the different ROIs in a volunteer (top) and a patient (bottom). (d) A band-pass filter is applied to the cardiac signal without projections cropping for comparison in the patient.

Results: Fig 2c shows the automatically detected cardiac motion signal using the proposed approach at different size of FOV in both volunteer (top) and patient (bottom). As the ROI gets closer to the myocardial contour, the cardiac signal gets better due to decreased interference from unwanted signals. Fig 2d shows the cardiac signal obtained using a band-pass filter using the full FOV, which presents more challenges for motion detection. The proposed approach particularly improves motion detection in the patient. Fig 3 shows the automatically detected cardiac and respiratory motion signal according to the temporal frequency and Fig 4 shows the end-systolic/diastolic frame reconstructed using the spokes detected at the local minimum and maximum positions.

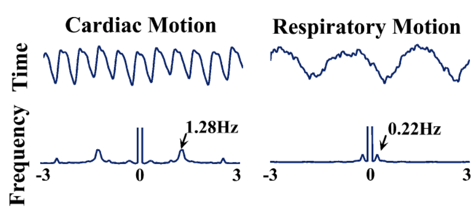

Fig. 3: Automatic motion signal selection according to the frequency information. Signals with the highest peak centered between 0.6-2.6Hz and 0.1-0.5Hz are selected as the cardiac and respiratory motion signals

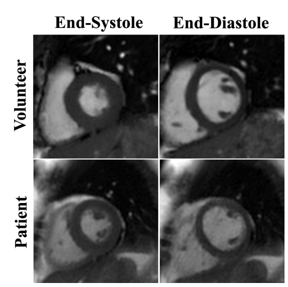

Fig. 4: End-systolic and end-diastolic phase reconstructed using the local minimum and local maximum from the signal in both volunteer and patient.

Conclusion: We proposed a robust and automatic cardiac and respiratory motion detection framework for self-navigated free-breathing cardiac imaging. The framework could be used for self-gating or data sorting in radial MRI of patients with arrhythmias and offers a feasible alternative to ECG for 7 Tesla cardiac MRI.

Reference: [1] Runge VM et al. MRM Radiology 1984;151:521–523. [2] Snyder CJ et al. MRM 2009 Mar;61(3):517-24. [3] Larson AC et al. MRM 2004 Jan;51(1):93-102. [4] Liu J et al. MRM 2010 May;63(5):1230-7.