k-t Reconstruction of Undersampled Wavelet-space for Real-time Free-breathing Cardiac Imaging

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Target Audience: Researchers in the field of cardiac imaging and image reconstruction.

Purpose: To develop a new wavelet-space image reconstruction technique for real-time free-breathing cardiac imaging.

Introduction: It is desirable to use real-time free-breathing data acquisition in cardiac imaging. The benefits include the ability to scan patients who cannot hold their breath (e.g. neonates), and fewer artifacts associated with data inconsistency in different cardiac or respiration cycles. Real-time free-breathing cardiac imaging requires the collection of a whole set of data in <100 ms for each time frame, posing image reconstruction challenges due to high undersampling. This work introduces a new technique that performs image reconstruction in an undersampled wavelet space. Since the required temporal sampling rate is lower in the wavelet space than that in the original k-t space, multiple neighboring time frames may be used as parallel channels to reconstruct a single time frame using k-t space parallel imaging approaches[1,2]. This reduces the effective undersampling rate in image reconstruction. The final image is generated from the undersampled wavelet-space images using an inverse wavelet transform.

Methods: Figure 1 illustrates the data acquisition and image reconstruction scheme for real-time free-breathing cardiac imaging. The collected data are transferred to the wavelet space by a wavelet transform (real-time wavelet decomposition filters). It should be noted that the frequency bandwidth of wavelet-space data is reduced by a factor of 2^L (L is the wavelet transform level), implying a lower temporal sampling rate is needed. As a result, parallel imaging may use neighboring time frames as parallel channels with different sampling trajectories (grey zones in Figure 1). This reduces the effective k-space undersampling rate in image reconstruction. The undersampled wavelet-space data are then used to generate the full k-t space data using an inverse wavelet transform (real-time wavelet reconstruction filters).

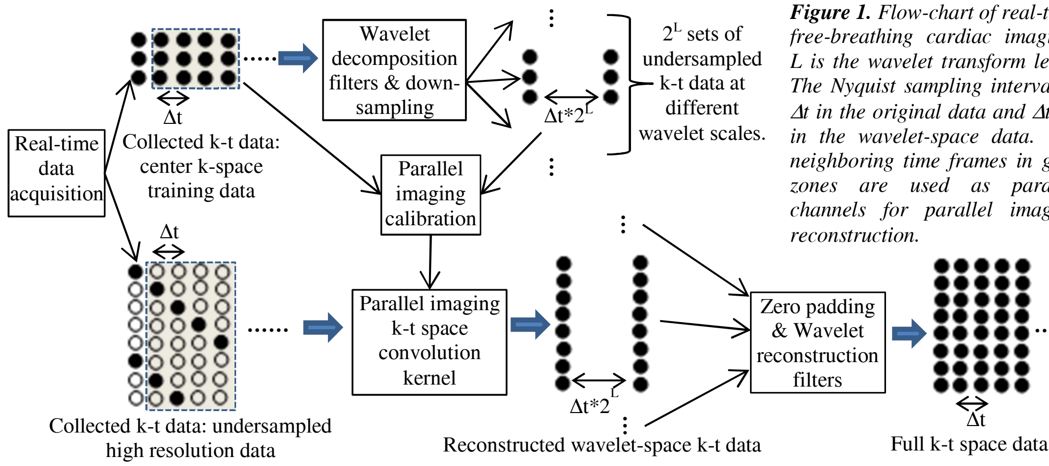

Figure 1. *Flow-chart of real-time free-breathing cardiac imaging. L is the wavelet transform level. The Nyquist sampling interval is Δt in the original data and Δt*2^L in the wavelet-space data. The neighboring time frames in grey zones are used as parallel channels for parallel imaging reconstruction.*

To demonstrate feasibility, a cardiac imaging experiment was conducted using a 32-channel cardiac coil array and a 3T clinical MRI scanner. Segmented cardiac CINE data were collected for references using a single-slice 2D ECG-gated bSSFP sequence (FOV 320×320 mm, matrix 160×160, TR/TE 2.3/1.2 ms, TFE factor=20, flip angle 30°, scan time 8 s, 30 cardiac phases). Simulation was first implemented by manually undersampling the full k-space segmented data. Free breathing cardiac CINE data were collected using a single-slice 2D T1 enhanced gradient echo sequence (FOV 320×320 mm, matrix 160×160, TR/TE 3.4/1.9 ms, flip angle 15°, acceleration factor 16, 7 training phase encoding lines, scan time 2 s). Because raw data are not available in real-time with our current hardware configuration, real-time image reconstruction was simulated by importing the stored raw data to an offline reconstruction program at a rate and format emulating that of online data acquisition.

Results: Figure 2 shows the experimental results. We found an average SNR drop of ~ 40% in images from simulated data and ~50% in those from real free-breathing data in reference to segmented imaging results. Considering an undersampling factor of 16 is used, the new approach provides a SNR gain of ~25%. In comparison to segmented results, wavelet-space reconstruction preserves dynamic information well (time trajectory in Figure 2d). Severe image distortion was found in online reconstruction using conventional k-t space techniques (k-t SENSE[1] in Figure 2c).

Discussion: The frequency bandwidth of temporal motion determines the temporal Nyquist sampling rate in cardiac imaging. Wavelet decomposition generates multiple datasets with a smaller frequency bandwidth than the original data. As a result, wavelet-space parallel imaging may be optimized for image reconstruction of motion information within a narrow frequency band, thereby allowing for the use of neighboring time frames in the collected k-t space data. This improves SNR without a considerable loss of dynamic information. Since wavelet-space reconstruction requires 2^L parallel imaging operators, the cost is computation time. This may be reduced using fast algorithms based on a polyphase wavelet transform[3].

Conclusions: This work demonstrates the feasibility of real-time free-breathing cardiac imaging using wavelet-space image reconstruction. We are working on the online implementaion of this approach for further clinical evaluation.

Reference: 1 Tsao, J et al., MRM 2003, 50: 1031-1032. 2. Huang, F et al., MRM 2005, 54: 1172-1184. 3.Akansu AN, et al., IEEE Trans. On Signal Processing 1992; SP-40.

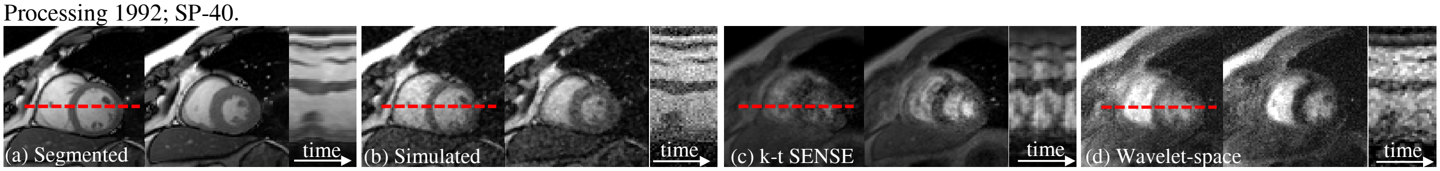

***Figure 2**. Image reconstruction results from online segmented cardiac imaging (a), simulated reconstruction from manually undersampled data (b), online k-t SENSE with free-breathing cardiac imaging (c), and wavelet-space approach with free-breathing cardiac imaging (d). From left to right in each figure are a reconstructed image at the end of diastolic phase, that at the end of systolic phase, and a reconstructed time trajectory of the red dashed line.*