Dynamic Cardiac Imaging Using Phase-Modulated Undersampled x-f Spectra from Multiple Cardiac Cycles

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Introduction: Dynamic images of moving objects often exhibit significant correlation in their k-spaces and time, which enables improved temporal resolution through faster sampling of the dynamic object by acquiring undersampled images. Developed methods such as UNFOLD[1] reconstruct these images through filtering of their x-f spectrum, while methods such as k-t BLAST[2] de-alias the x-f spectrum by applying prior knowledge as an estimation of the un-aliased spectrum. This work is to provide an alternative approach of imaging and reconstruction by performing a spectral analysis toward the x-f spectra of different cardiac cycles.

Theory: Figure 1 demonstrates the k-t space sampling patterns and their corresponding x-f spectra with a 4-fold acceleration, which consist of the un-aliased original spectrum and its replica. Every cycle is acquired by a shifted sampling pattern relative to its previous cycle, resulting in a linear phase shift being applied to the replica of the un-aliased spectrum. By applying a Fourier Transform to the series of x-f spectrum, each replica can be seen to oscillate at a different frequency. Therefore, it is possible to separate the results which correspond to the un-aliased original x-f spectra by post-processing (See Fig 2).

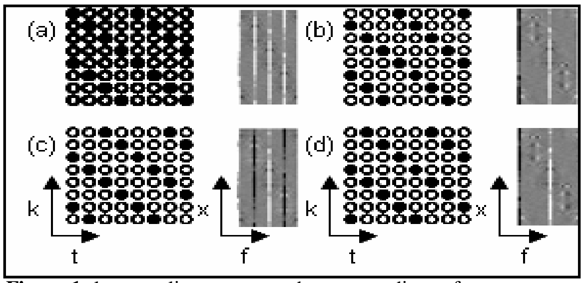

Figure 1: k-t sampling pattern and corresponding x-f spectrum of different cardiac cycles (a) cycle 1, and (b)(c)(d) shifted versions of fig 1-a. Note the difference among the "banding" of their x-f spectra due to phase modulation induced by shifted sampling

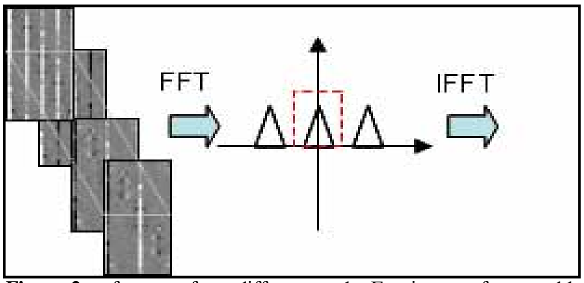

Figure 2: x-f spectra from different cycle. Fourier transform enables the separation of original spectrum from different replica. The filtered resulted is then inverse transformed to gain the un-aliased x-f spectra.

Method: Four healthy volunteers (aged 23-27 years) given informed consent were scanned. In order to test the new reconstruction approach, full sampled datasets were acquired through a protocol of breathhold, gated 2D TrueFISP short-axis cine sequence., with 30 cardiac phases, a 35 degree flip angle, a matrix size of 256 x 192, and a slice thickness of 10mm. Subsets of these fully sampled datasets were then used in the reconstruction to simulate reduced acquisition. Several datasets with displacement (about 5%) were deliberately created to test the effect of spatial misregistration on reconstruction. All measurements were performed on a Philips Achieva 3T whole-body scanner.

Results: Figure 3 depicts the reconstruction error of the proposed method simulating 8-fold undersampling. A simulated reconstruction using k-t BLAST was generated with the same set of data to serve as a comparison, while training data required for k-t BLAST were also produced from subsets of the previous fully sampled datasets. Reconstruction error was calculated by:

$$E_{RMS,t} = \sqrt{\frac{\sum_{i=1}^{N} |r_{i,t} - o_{i,t}|^2}{\sum_{i=1}^{N} |o_{i,t}|^2}}$$

Where $r_{i,t}$ and $o_{i,t}$ denote the i'th pixel value at time frame t of the reconstructed and original images, respectively. The reported error is the mean of all examinees. A comparison of the results shows that k-t BLAST (fig 3(a)) results in less error during diastole with a lower overall RMS error, while the proposed method (fig 3(b)) depicts higher overall RMS error yet less error in systolic phases with substantially lower variances in RMS error. Figure 4 depicts the selected reconstructed images and error of the mis-registered datasets. The increase of RMS error k-t BLAST reconstruction with displacement (fig 4(a)) is consistent with previous reports [3], while error of proposed method (fig 4(b)) also increased, yet the variance of error within cardiac cycle remains relatively lower.

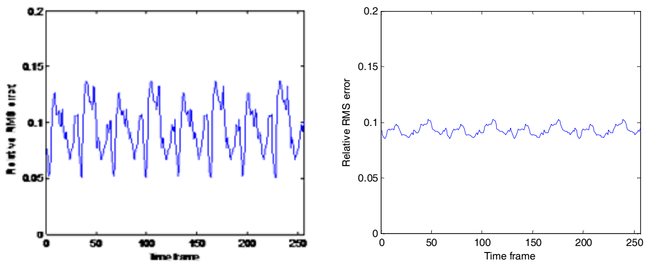

Figure 3: RMS error of (a) k-t BLAST (b) proposed method

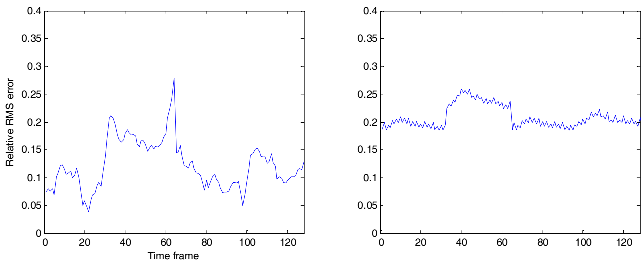

Figure 4: RMS error in the presence of mis-registration (a) k-t BLAST (b) proposed method

Discussion: The proposed method demonstrated a reconstruction with overall low variances in error and slight improvement in systolic phases. Nevertheless, its sensitivity to mis-registration is relevant to the proposed approach of spectral analysis among the cycles, where error from the mis-registered cardiac cycles seems to spread over all cycles involved in the inverse Fourier Transform. As a consequence, increment of cycle number enhances SNR and accuracy at the cost of somewhat longer scan time and increased risk of mis-registration from involuntary motion.

Reference:

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