Variable Density Sampling in Radial k-t GRAPPA

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Introduction: Radial imaging is attractive since it is less sensitive to motion and potentially can retrospectively increase temporal resolution. Radial GRAPPA [1] and radial *k-t* GRAPPA [2] have been proposed to reduce artifacts in undersampled radial imaging. Either extrally acquired or calculated [2] full *k*-space calibration data are necessary in these existing techniques. Variable density (VD) sampling has been proposed for auto-calibration in Cartesian imaging. In this work, we extended this technique to radial *k-t* GRAPPA to avoid the extra acquisition or calculation of calibration signal. Experimental results demonstrate the feasibility of the proposed method.

Theory: In Cartesian GRAPPA [3], several ACS (auto calibration signals) lines in the central k-space are used to generate weights for linear combination of neighboring lines. Adopting this concept in radial sampling, we acquired additional radial lines as ACS lines along with other regularly spaced radial projections.

In cartesian *k-t* GRAPPA [4], different sets of phase-encoded lines are acquired at successive time points. Similarly, in radial *k-t* GRAPPA, the angle at which radial data are acquired changes at different time frames. For each time frame there is a fixed fully acquired radial band of ACS lines. This method does not require a pre-scan, so is efficient in cardiac application. For image reconstruction, we first re-order the radial dataset to Cartesian form. To include more ACS lines to improve the accuracy of reconstruction, we divide the whole *k*-space into two parts along azimuthal direction , each derives its own *k-t* GRAPPA weights. An example with a reduction factor of 2 is shown in Fig 1. Solid lines in Fig.1 (a) show the acquired projections while dashes lines show the undersampled projections. Blue stripes illustrate how radial data are correspondingly reordered into Cartesian sets. Black dots in Fig. 1(b) are the acquired data, stars show the fully acquired ACS projections, the circles show the missing data. And the arrows give examples of the adjacent data used to interpolate a missing line. If there are multiple coils, then all of those coils have the same sampling pattern. The final images are reconstructed by regridding after all the missing projections have been calculated.

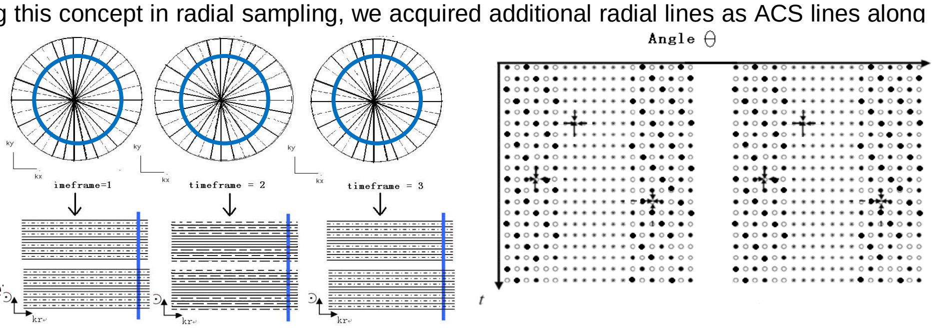

Fig.1. The k-t radial sampling trajectory with reduction factor equals 2. (a) Radial sampling pattern in k-space for 3 consecutive time series. (b) Radial sampling pattern shown in sampling degree and time domain.

Methods: Breath hold cine images were acquired on a Siemens TIM Trio magnet with 2D True FISP Radial sequence with 128 projections and 512 points per projection. The field of view was 30cm, flip angle was 65 degrees, slice thickness 5mm ,TR =36.64msec,TE=2.29msec. Two datasets were acquired, before and after contrast enhancement separately with a 4-channel cardiac coil, and each had 17 cardiac phases. Artifically undersampled data were used for reconstruction. Reduction factor 2, 4, and 8 (64, 32, 16 projections respectively) were used. In this case, totally 16 extra projections were used out of 128 projections for calibration. Visual assessment from an objective observer was applied to these two. Grades ranged from1 to 4, 0.5 interval. The relative error (defined as the ratio of the SSoS of all pixels of the difference map to the SSoS of all pixels of the reference image) was calculated.

Results: One random timeframe from one of the datasets is used to show the reconstruction result. The reference image (reconstructed with all the projections available) and reconstruction results with reduction factor of 2,4,8 from timeframe 9 are shown in Fig 2. Results of the average of the visual assessments and relative errors from all timeframes in both datasets are shown in Fig 3. The blue lines show the 1st dataset while red lines show the 2nd dataset which is after contrast enhancement. The mean visual grades for reference image and reconstruction results with reduction factor 2 are close to 4. It drops to 1 for results with reduction factor 8. The relative error ranges from 0.006 for reduction factor 2 to 0.14 for factor 8.

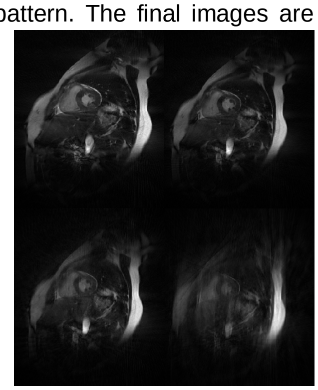

Fig.2. Images from time frame 9 in dataset 1. From left up to right down are reference image and k-t GRAPPA images with reduction reduction factors 2, 4, and 8.

Discussion and Conclusions: It has been shown that this variable density sampling pattern of radial k-t GRAPP is applicable and efficient in implementation. In aspects of visual assessment of image quality and relative error, reconstruction results with reduction factor 2 are nearly the same with reference images, while there are no significant difference when reduction factor is no larger than 4. k-t GRAPP with variable density sampling is a useful technique for cardiac cine imaging.

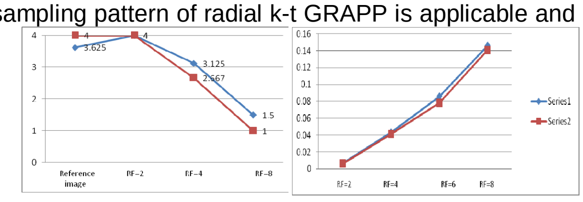

Fig.3. (a) The visual assessments for dataset 1 (blue lines) and dataset 2 (red lines). (b) The relative error calculated from two datasets with reduction factors2, 4, 8.

References:

[1] Griswold et al, ISMRM,p.2349 (2003)
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[4] Huang F et al. MRM 54:1172–1184. (2005)