

Accelerated EPRI Using Partial Fourier Compressed Sensing Reconstruction

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Introduction: In Electron Paramagnetic Resonance Imaging (EPRI), single k-space point is typically acquired per excitation due to the very short T2's of the free radicals [1]. The single point acquisition scheme lengthens total scan time, and poses a challenge especially when studying dynamic changes within a tumor microenvironment, e.g. cycling hypoxia where the pO₂ level fluctuates from normoxic to hypoxic levels within a time scale of 30 sec to 1 min. Partial Fourier reconstruction was the first method of choice for scan acceleration, but the possible acceleration rate was limited (~2)[2]. Compressed sensing (CS) is another promising approach for EPRI acceleration since the single point acquisition offers huge degree of freedom for under-sampling patterns that are crucial for CS. This study aimed to develop a high-rate acceleration method for dynamic EPRI by combining partial Fourier and CS techniques.

Materials and Methods: Reconstruction: The proposed combination of partial Fourier and CS builds on the virtual coil concept introduced for partial Fourier reconstruction [3]. The virtual coil concept utilizes the conjugate k-space symmetry by augmenting the original system equations with fabricated measurements made of conjugate symmetric signals. The advantage of this framework is that partial Fourier reconstruction is formulated as typical linear systems which can easily incorporate a regularization term such as total variation. The proposed partial Fourier+CS (pfCS) minimizes the cost function written as $\|y - Ex\|^2 + \lambda \cdot TV(x)$. y is the augmented data measurements $[y, y^*]^T$ where y is the actual k-space measurement and y^* is its complex conjugate. E is encoding matrix written as $\begin{bmatrix} F & 0 \\ 0 & F^* \end{bmatrix} \begin{bmatrix} P \\ P^* \end{bmatrix}$ where

F is Fourier operator and P is pixel-by-pixel phase multiplication. The system equation can be solved iteratively using non-linear conjugate gradient method [4]

Experiment: All data were acquired using a home built EPRI scanner operating at 300MHz at a Zeeman field of 10.6mT. A resolution phantom was imaged in 2D with 61x61 phase encoding steps. For *in vivo* imaging, a 25g mouse with tumor cell implanted into the left hind leg were imaged right after Oxo63 (60mMol/100ul) injection in the tail vein. Seven 2D volumes were acquired with 61x61 phase encoding steps (2min for each volume). Full k-space data were under-sampled with an acceleration factor of 4 and 6 (9% biased towards the center of k-space and random sampling elsewhere). For *in vivo* datasets, pfCS estimated the phase map (P in the system equation) from the first fully sampled time point and was used for all subsequent under-sampled time points. Performance of the CS and pfCS reconstruction was compared based on the root mean square error (RMSE) with the true image reconstructed from the full k-space.

Results: Figure 1 shows the reconstructed resolution phantom image. The CS reconstructed images are blurred, while pfCS retains mostly of the structure information with the 300micron gap resolution bars being clearly visible, using only 17% of original data points. Figure 2 shows the 2D *in vivo* EPRI images at time point 7. CS again shows blurred images with significant loss of edge information around the fine structures. Even though only the phase map from the first time point was used, the pfCS reconstruction produced lower RMSE for all time points and better details in the images even with 17% k-space data. The comparison of CS and pfCS for all time points in the 2D *in vivo* data was shown in Figure 3, with 25% and 17% sampling of original data points.

Discussion and Conclusion: A challenge of the direct CS implementation in EPRI is the low spatial resolution in EPRI images, which yields unacceptable level of aliasing signals with typical variable density under-samplings. We have demonstrated that combining CS with partial Fourier reconstruction significantly improves the reconstruction accuracy by improving the reconstruction conditioning. We can maintain reasonable data quality with as little as 17% of data sampling (an acceleration factor of 6) in EPRI, making dynamic imaging of cycling hypoxia feasible with 20-30 second temporal resolution for 2D and 3D acquisitions. From our experimental observation we notice very little phase variation with time in the dynamic images, which may explain the good performance of the pfCS methods when only the phase map of the first time point was used. More investigation is needed to examine the effect of phase variation to pfCS reconstruction. Future work will also include further evaluating pfCS on quantitative measurements of the pO₂.

Reference: [1] Subramanian S, et al. Single Magn Reson Med. 2008; 48:370-379. [2] Subramanian S, et al. Magn Reson Med. 2012 [3] Blaimer M, et al. Magn Reson Med 2009; 61: 93-102. [4] Lustig, et al, Magn Reson Med.. 2007; 58:1182-1195

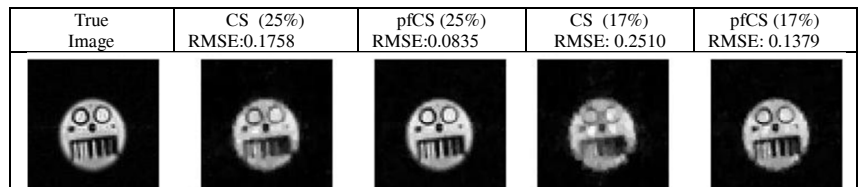


Figure 1. 2D resolution phantom EPRI images reconstructed with CS and pfCS at 25% and 17% of data under-sampling.

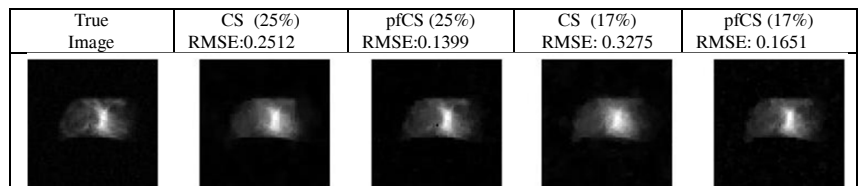


Figure 2. 2D *in vivo* EPRI images at time point 7, reconstructed with CS and pfCS at 25% and 17% of data sampling.

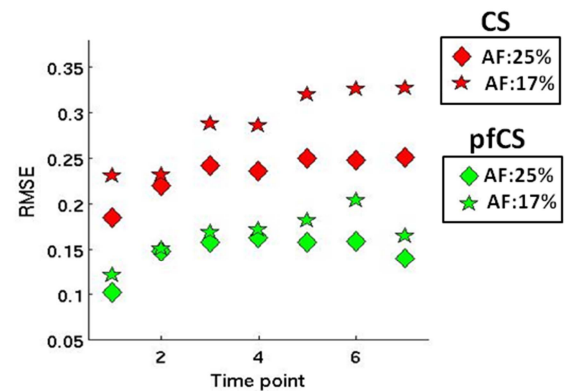


Figure 3. RMSE value of 2D *in vivo* data with under sampling rate 25% and 17% for different time point.