PILARS: Parallel Imaging with Large ARrays and Sinc-interpolation

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Introduction: Large arrays make it possible to use parallel imaging to significantly accelerate MR imaging speed. K-domain reconstruction methods for parallel imaging such as GRAPPA [1] and MCMLI [2] are able to provide robust reconstructions. However, actual achieved acceleration factor is limited as the number of auto-calibration signals (ACS) is proportional to the acceleration factor and kernel size. This limitation is undesirable for large arrays with potentially high acceleration factors. This paper represents a novel reconstruction method for large array parallel imaging that uses Sinc kernels to interpolate k-space data. Interpolation coefficients are predetermined based on Sinc function with a phase parameter which can be obtained in an automated manner from a single ACS. Phantom experiments using a 64-channel system show that it provides higher acceleration factors, comparable reconstruction quality, and fast reconstruction speed.

Theory and Methods: In the proposed method, the k-space data corresponding to the full FOV is recovered by

$$\hat{s}(m,n) = \sum_i \sum_j s(i,j) \, \text{sinc}\left(\frac{\pi}{D_1}(m-i)\right) \text{sinc}\left(\frac{\pi}{D_2}(n-j)\right) e^{j2\pi\left(x_o \frac{(m-i)}{N} + y_o \frac{(n-j)}{N}\right)} \tag{1}$$

where $m,n = 1,2,...,N$, are the indices of phase and frequency encodings, $i = D_1, 2D_1, ..., N$, $j = D_2, 2D_2, ..., N$ are the indices of acquired data s with acceleration factors D_1 and D_2 along the two dimensions, and (x_o, y_o) is the center of a rectangular window that covers the sensitivity area of an individual coil. Note that this reconstruction formula utilizes all acquired data in the k-space and the coefficients are determined by the sinc function and a phase term only. In the proposed method, the phase term is estimated in two stages. First, a folded coil image is reconstructed from all acquired data including the ACS. The maximum amplitude point in the folded image is used to find an approximate coil center $(\hat{x}_o, \hat{y}_o)$. Then, (x_o, y_o) is estimated in the vicinity of $(\hat{x}_o, \hat{y}_o)$ by solving

$$\underset{(x_o, y_o)}{\arg\min} \; \| \hat{s} - s_{ACS} \|_2 \;, \text{ where } (x_o, y_o) \in \left([\hat{x}_o - N/D_1, \hat{x}_o + N/D_1], [\hat{y}_o - N/D_2, \hat{y}_o + N/D_2]\right) \tag{2}$$

where s_{ACS} is the calibration data and $\hat{s}$ is the reconstructed data at the same location using Eq.(1). The calibration is done once for each channel and reconstruction is processed channel by channel. The final image is combined from individual coil images using sum-of-squares.

A set of fully sampled 256x256 data was acquired on 4.7T system using 64-channel receiver coil array. Accelerated acquisition was simulated by decimation along only in phase encoding direction. Results by MCMLI with 30 ACS lines and 2x4x3 (FExPExCh) reconstruction kernels were used for comparison [3]. For robustness, a single block of ACS was used in the experiment. All processing were performed on a 2.6GHz Dual-core CPU with 2 GB memory in Matlab (Math Works, Natick, MA). Reconstruction from the fully sampled data was used as reference and reconstruction errors were calculated as normalized root mean square error (NRMSE).

Results: Reconstruction results are given in Fig.1. Results from MCMLI show slightly less artifact and smaller NRMSE. However, two methods provide comparable reconstruction qualities in general. The corresponding net acceleration factors are shown in Table.1. As can be seen, as D increase, the actual achieved acceleration factors decrease rapidly for MCMLI while PILARS is able to maintain high acceleration factors. The reconstruction speed using PILARS is very fast. It took 10 seconds to reconstruct 256x256x64 data down sampled at D = 10 while the MCMLI method took 78 seconds.

Conclusion and Discussion: A novel parallel imaging method with predetermined Sinc kernels is presented for large arrays with localized coil sensitivity. Compared to traditional k-domain methods, PILARS achieves higher acceleration factors and faster reconstruction speed with similar reconstruction quality. The method can be interpreted as applying a truncation window in spatial domain as in the PILS method [4]. Therefore, it is expected to have similar SNR advantage as in PILS recon. However, it does not suffer from the potential blocking artifacts and the need for shifting coil images as the PILS method does.

Table.1 Net Acceleration Factors

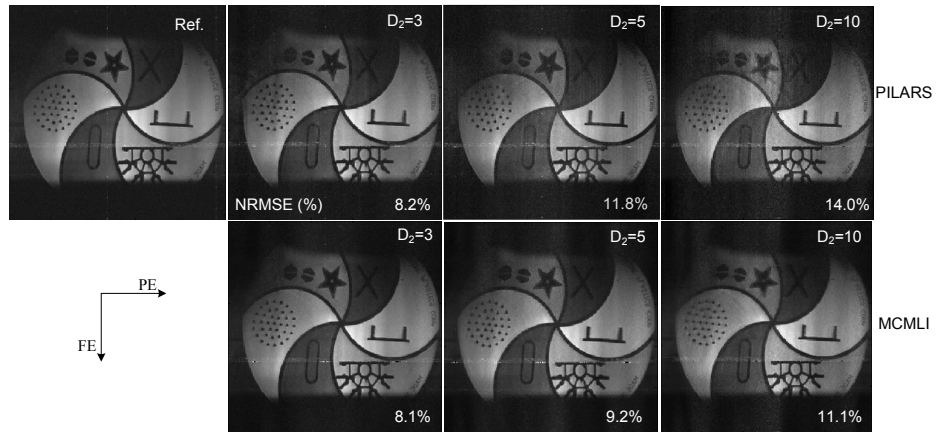| D_2	PILARS	MCMLI
3	3.0	2.4
5	4.6	3.4
10	7.4	4.9

Figure.1 *Reconstructions using the proposed PILARS method and MCMLI method from a set of 64-ch coil array data. NRMSEs are shown.*

Reference:
[1] M. Griswold, *et al.* MRM 2002; 47:1202-10
[2] Z. Wang, *et al.* MRM 2005; 54:738-742
[3] S. Feng, *et at.* MRI 2010; In press
[4] M. Griswold, *et al.* MRM 2000; 44:602-09