Parallel Imaging with Partial Fourier Acquisitions for 3D MRI

H. H. Hu[1], A. J. Madhuranthakam[1], C. R. Haider[1], D. G. Kruger[1], S. J. Riederer[1]

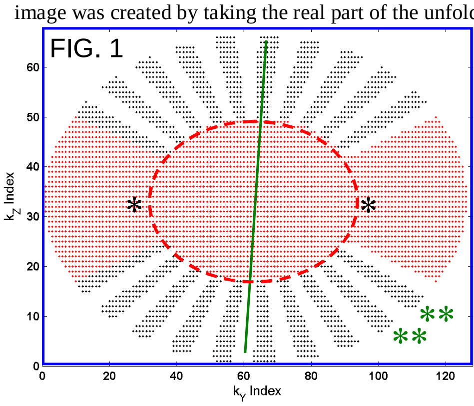
[1]Dept. of Radiology, Mayo Clinic College of Medicine, Rochester, Minnesota, United States

Introduction

SENSitivity Encoding (SENSE) and partial Fourier (PF) are techniques both aimed at accelerating the acquisition of k-space to reduce scan time and improve spatial resolution in MRI. The former uses complex coil sensitivity profiles of the B1 field to unfold aliased pixels from decreased-FOV acquisitions [1]. The latter uses Hermitian properties of k-space and homodyne detection to restore missing k-space data after phase correction [2,3]. Previous work [4] has addressed the need to perform SENSE reconstruction prior to homodyne phase correction, since the latter removes phase information critical to SENSE. More recently, another parallel-imaging technique GRAPPA [5] has been integrated with PF to form 2D brain images [6]. This present abstract extends the combination of SENSE and PF to 3D MRI. Specifically, PF is applied along both the phase (Y) and slice (Z) encode axes, while twofold SENSE is achieved along Y. In vivo results demonstrate a potential 72% reduction in scan time using SENSE-PF over a non-accelerated fully-sampled 3D acquisition with comparable image resolution.

Methods

Fig.1 shows our reduced sampling pattern in the k_Y-k_Z domain, which is based on a previously described acquisition [7]. For discussion, consider an example with a 256(X read)×128(Y phase)×64(Z slice) matrix. Only views denoted by the dots are sampled, which constitutes ~56% of the full k_Y-k_Z grid (blue rectangle). The red region contains ~35% of the total number of sampled views, but can be arbitrarily selected by adjusting the center sector angles (*). No reduction in sampling is performed in this region for the purpose of preserving SNR that are lost due to PF and SENSE processing. The outer radial sectors used for this work are approximately 6 degrees wide (**), with those sampled in the upper hemisphere anti-symmetric to those sampled in the lower hemisphere (green line). This anti-symmetry facilitates the homodyne detection process. With twofold Y-SENSE, the Δk_Y-spacing represented in Fig.1 is $2 \cdot \Delta k_Y$ ($R_Y = 2$), where Δk_Y is the sampling interval of the reference non-accelerated case. This sampling scheme was tested using a 3D GRE sequence with TR/TE = 21/6 ms, $\alpha = 10^0$, BW = ±16 kHz, coronal slice = 2 mm, FOV = 30 cm, and a 256×128×64 matrix. For image comparisons, five cases were considered. The term "*fully sampled*" refers to non-accelerated and SENSE-only accelerated scans where all views in a given k_Y-k_Z grid are sampled (Case 1-3). The term "*reduced sampling*" implies the scheme in Fig.1 (Cases 4-5). The acquisition time (T_{ACQ}) for each case is shown with respect to Case 1. PF-SENSE data from each coil was processed separately. In the first reconstruction, only views in the central region (dashed ellipse in Fig.1) were Fourier transformed into image space. In a second reconstruction, homodyne detection was performed on the remaining data by weighting asymmetrically sampled views by two. At this point, using all receiver images, both first and second reconstructions were individually unfolded with SENSE. The final image was created by taking the real part of the unfolded second reconstruction after phase correction using information from the unfolded first reconstruction.



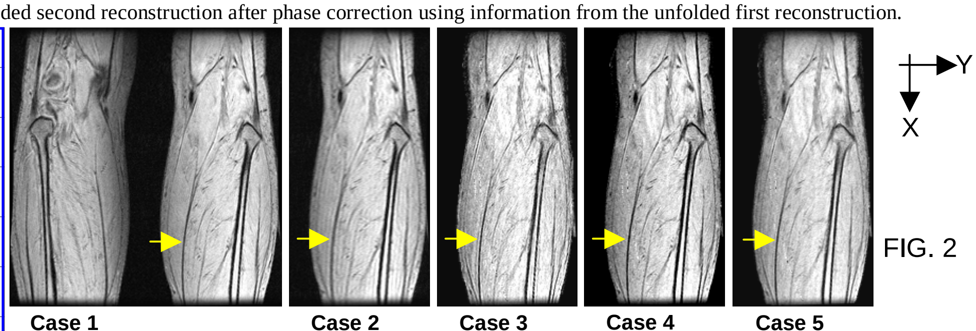
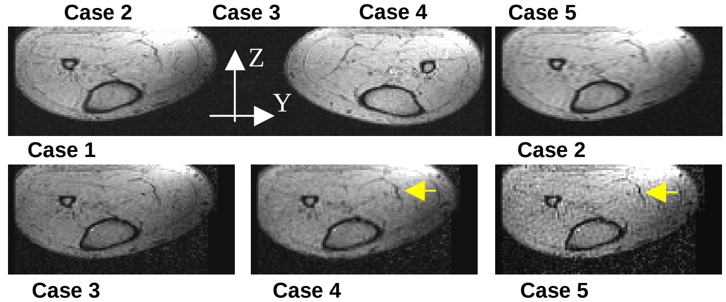


FIG. 2

FIG. 3



Case 1: Ref. scan, *fully sampled* 256×256×64, $\mathbf{T_{ACQ}}$.

Case 2: Ref. scan, *fully sampled* 256×128×64, **50%** $\mathbf{T_{ACQ}}$.

Case 3: *Fully sampled* 256×128×64, SENSE unfold to 256×256×64, **50%** $\mathbf{T_{ACQ}}$.

Case 4: *Reduced sampling*, 256×128×64, SENSE unfold to 256×256×64, **zero-fill** non-sampled views, **28%** $\mathbf{T_{ACQ}}$.

Case 5: *Reduced sampling*, 256×128×64, SENSE unfold to 256×256×64, **homodyne detection** for non-sampled views, **28%** $\mathbf{T_{ACQ}}$.

Results

Coronal and reformatted axial images are shown in Figs. 2 and 3, respectively. For Cases 2-5, only one leg is shown. In the coronal images, the benefit of improved resolution with SENSE is demonstrated. Note that in Cases 3-5 where SENSE was implemented, minimal fold-over reconstruction artifacts are present. Furthermore, Cases 3-5 exhibit similar Y resolution compared to the fully sampled 256-point phase encoded reference in Case 1, and improved resolution vs. the 128-point phase encoded Case 2 (arrows). Use of homodyne detection to significantly reduce scan time with SENSE is illustrated in both coronal and axial images with Case 5. In Fig. 3, homodyne yields sharper structures (Case 5) than zero-filling (Case 4) (arrows), however at the expense of increased noise and decreased signal intensity throughout the image. Nevertheless, the fact that Cases 3-5 were acquired in 50%, 28%, and 28% T_{ACQ} of the fully sampled Case 1, respectively, while producing comparable resolution, demonstrate the promise of parallel imaging with partial Fourier to improve k-space sampling efficiency in numerous MRI applications.

Conclusion

Results have demonstrated the synergistic effect of SENSE and partial Fourier imaging to reduce acquisition time and improve spatial resolution in 3D FT MRI. Both SENSE and PF suffer intrinsically from SNR loss during acquisition and reconstruction. Their integration is thus potentially limited to high SNR scans. Future work will investigate the use of SENSE-PF in high-resolution peripheral CE-MRA.

References

[1] Pruessman KP, et al. MRM 1999; 42:952-962.
[2] MacFall JR, et al. MRI 1988; 6:143-155.
[3] Noll DC, et al. IEEE TMI 1991;10:154-163.
[4] King KF, et al. Proc. ISMRM 2000:153.
[5] Griswold MA, et al. MRM 2002; 47:1202-1210.
[6] Bydder M, et al. Proc. ISMRM 2004:532.
[7] Madhuranthakam AJ, et al. Proc. ISMRM 2004:8.