Implementation of Underdetermined SENSE: Clinical Examples from Brain Imaging

J. S. van den Brink[1], T. Rozijn[1], F. Visser[1], K. Bloemers[1], M. Fuderer[1]
[1]Magnetic Resonance, Philips Medical Systems, Best, Netherlands

Introduction

Sensitivity Encoding (SENSE [1]) is widely used in routine clinical imaging [2] with reduction factors lower than the number of coil elements. It has been shown from simulations that the use of a high-quality *prior* image can in principle be used to allow for scanning with reduction factors higher than the number of coil elements, called *underdetermined* SENSE [3]. In this study, we implemented this technology on a routine clinical MR scanner, using a low-resolution prior image. It is demonstrated that reduction factors for 2D SENSE [4] can readily exceed the number of receive channels by 30-50%.

Theory

SENSE reconstruction is performed by obtaining the least-squares solution to the well-known equation [1]: $p = (S^h \cdot \psi^{-1} \cdot S)^{-1} \cdot S^h \cdot \psi^{-1} \cdot m$, where S is the coil sensitivity matrix, m the measured data, p the reconstructed image data, and ψ the noise covariance matrix. Rather than extending the equation with a *prior* image estimate, and iteratively minizing the cost function of the reconstruction [3], we extended [5] the above equation with prior knowledge of the imaging object as obtained from the coil sensitivity reference scan, i.e. $p \approx m_L$, where m_L is the corresponding intensity in the reference scan. The extended least-squares estimate directly gives $p = (S^h \cdot \psi^{-1} \cdot S + R^{-1})^{-1} \cdot (S^h \cdot \psi^{-1} \cdot m + R^{-1} \cdot m_L)$. The result of this addition is that the reconstruction is always well-defined, even if the reduction factor exceeds the number of coil elements.

Methods

Imaging was performed on a Philips Intera 1.5T, equipped with an 8-channel spectrometer. A 6-channel SENSE Head Coil was used to show the feasibility of underdetermined SENSE. The only modification made to product SW was to allow SENSE reduction factors to exceed the number of active channels. All scans used constant k-space density. Two clinical scan protocols were tested, viz. 3D Phase-Contrast Venography, and 3D T1-FFE. The scan parameters for the Venography sequence were: scan time: 2:30; SENSE 7 (2.35-RL*3.0-AP); TE/TR/α = 7.3/15/10; 3D RF-spoiled FFE; Venc = 10 cm/s in all 3 directions; FOV = 170; matrix 160 (acquisition)/256 (reconstruction); 200 slices of 1.2 mm overcontiguous. The 3D T1-FFE parameters were scan time: 2:39; SENSE 8.1 (2.7-RL*3.0-AP); TE/TR/α = 4.6/25/30; 3D RF-spoiled FFE; FOV = 260; matrix 240 (acquisition)/256 (reconstruction); 182 slices of 1.0 mm. Volunteer scanning was approved according to local guidelines. Coil sensitivity maps were acquired using a 10 second 3D FFE reference scan with isotropic voxel size of approx 6 mm. This data is reformatted in the reconstruction process to the scan orientation of the clinical protocols, and the reformatted data from the QBC part of the reference scan is used as *prior* image.

Results

Fig 1 shows transverse, sagittal and coronal MIP images from the SENSE 7 3D PCA venography scan. No residual backfolding is observed in the MIPs, nor any (excessive) noise enhancement.

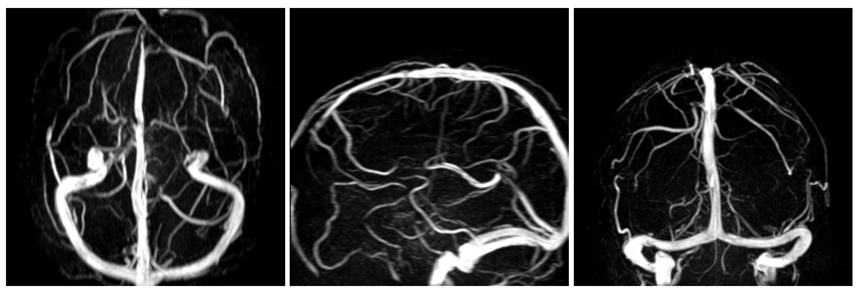

Figure 1 ***SENSE 7*** *Phase Contrast Venography MIPs*

Fig 2 shows 3 source images from the isotropic resolution (1mm^3) SENSE 8 3D FFE scan. Again, note the absence of any residual backfolding artefacts. The data set does not show significant noise hot spots, i.e. the geometry factor is low anywhere in the brain.

Figure 2 ***SENSE 8*** *Isotropic voxel T1-FFE source images*

Discussion and Conclusion

The Figures shown before demonstrate that SENSE reduction factors are not limited to the number of coil elements, or number of independent receiver channels. 2D SENSE unfolding quality appears to be adequate: no residual ghosts, and no noise enhancement patches (high geometry factors). Reduction factors can exceed the number of independent receiver channels by 30-50%. Thus, Underdetermined (2D) SENSE implies a major opportunity for significant speed increases beyond previously known boundaries. Clinical application of the technique is limited by available SNR, and anticipated clinical use. Further work is performed to use the underdetermined SENSE capabilities on 8 and 16 channel coils which provide sufficient SNR to achieve double-digit reduction factors in volume localizer images and flow imaging.

References

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