High Pass SENSE

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Introduction Artificially increasing the sparsity of an image before reconstruction has been used to improve the performance of partially parallel imaging techniques [1, 2]. Similar to the requirement of explicit sensitivity maps, an explicit image support (non-zero regions) definition is also required to take fully advantage of image sparsity in conventional SENSE [3]. However, it is not trivial to provide an accurate image support definition. To overcome this challenge, this work uses regularized SENSE as proposed in Ref [4], which adopts a regularization image. A sparse image, which was generated by high pass filtering and g-factor map suppression, is used as the regularization image. The explicit definition of image support is avoided. Experiments show that the proposed method can reconstruct images with noise levels significantly lower than conventional SENSE. Excellent image quality has been achieved using an 8-channel head coil and a 1D net acceleration factor of R = 4.

Theory The regularization scheme proposed in Ref [4], Eq. 3, requires that the regularization image provides the relative intensity ratios among superimposed pixels. This requirement is much easier to meet than the explicit image support definition. This regularization scheme is adopted here to take advantage of the image sparsity. To show the image regularization procedure, a high resolution brain image acquired with an 8-channel head coil (Fig. 1a) is used as an example. First, a high pass filter [1] is applied to the partially acquired *k*-space data (R = 4). With the high passed data, SENSE can generate an image with reduced image support (Fig. 1b). In regions with high g-factor [3] and low signal, the noise has similar magnitude to the signal, which can be clearly observed from the image. Therefore, it is proposed to divide the initial reconstruction by the g-factor map to reduce the magnitude of noise. The result of the pixel-wise division (Fig. 1c, brightened for better visualization) shows a reduction of magnitude for regions with high g-factor value. Using this image as the regularization image, an image with reduced noise level (Fig. 1d, comparing to Fig. 1b) can be reconstructed by Eq. 3 in Ref [4]. The combination of the regularized reconstruction of the high-pass filtered data (Fig. 1d) and the reconstruction (using conventional SENSE) of the difference between the high-pass filtered and the original data generates the final image (Fig. 1e). This technique is named as high pass SENSE (hp-SENSE).

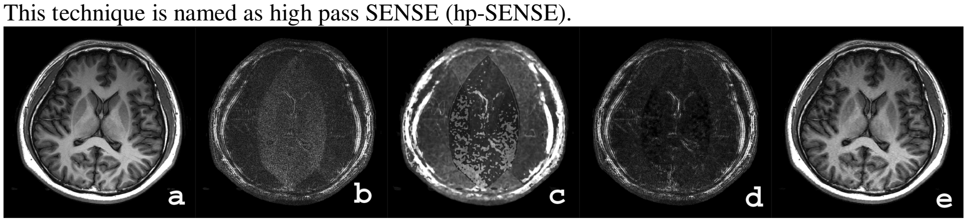

Fig. 1 Theory of high pass SENSE. Reconstruction with high passed k-space data has reduced image support (**Fig. 1b**). Noise with g-factor pattern has magnitude as high as signal. Division by g-factor map can partially correct magnitude (**Fig. 1c**) and is used as regularization image.

Methods Two sets of brain data were acquired on a 3.0T Achieva scanner (Philips, Best, Netherlands), using an 8-channel head coil (Invivo, Gainesville, FL) with the following scan parameters: FOV 230x230 mm^2, matrix size 256x256, TR/TE=2000/20 ms. IR sequence was used for both data sets. Two different inversion times were used to suppress gray matter (GM, TI = 800 ms) or fat (TI = 180 ms) respectively. Phase encoding direction was anterior-posterior. The fully acquired data set was artificially under-sampled with R = 4 to simulate the partially parallel acquisition. Pre-scan low resolution data set was used to calculate the sensitivity maps. For comparison, separate images were reconstructed using conventional SENSE [3], and high pass SENSE. The high pass filter was defined by Eq. 2 in Ref [1] with c=64 and w=6. The full *k*-space data was used to generate the reference image for root mean square error (RMSE) calculation.

Results Table 1. shows the comparison of RMSE of the images reconstructed by the different methods. Fig. 2 shows the zoomed in images. It can be seen that the images reconstructed by hp-SENSE (Figs. 2b, 2d) have clearly reduced noise/artifact level compared to conventional SENSE (Figs. 2a, 2c). With 1D net acceleration factor 4, no significant artifacts can be observed in the images reconstructed by hp-SENSE.

Table 1. RMSE comparison

	SENSE	hp-SENSE
GM suppressed	7.4%	5.8%
Fat suppressed	10.0%	7.0%

Discussion and Conclusion The combination of hp-SENSE and a regularization scheme, such as the one in Ref [4], provides an approach that takes advantage of image sparsity. Since no explicit image support definition is necessary, the spatial resolution of hp-SENSE reconstruction can be well-preserved while the noise level is dramatically reduced (Figs. 2b, 2d). Similar to hp-GRAPPA, the hp-SENSE reconstruction can be optimized by tuning the high pass filter. In conclusion, using an artificial sparsity technique, a SENSE based method is introduced which achieves a high signal to noise ratio at a high net acceleration factor.

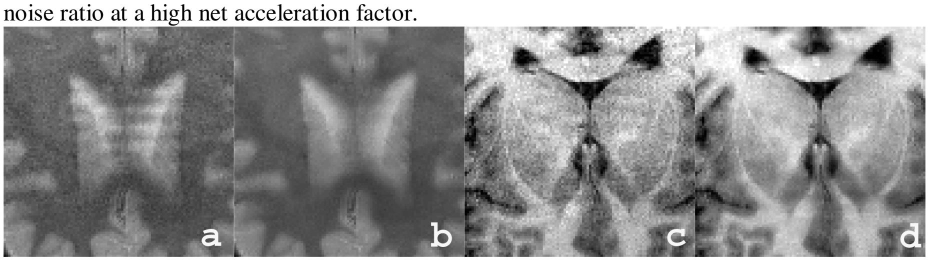

Fig. 2 Results with 1D net acceleration factor 4. (a, c) results of conventional SENSE; (b, d) results of high pass SENSE

References

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