SENSE reconstruction using feed forward regularization

M. Fuderer[1], J. van den Brink[1], M. Jurrissen[1]
[1]MR development, Philips Medical Systems, Best, Netherlands

Introduction

In MRI, the reconstruction of SENSE data can lead to local noise enhancement in some image regions. This is particularly the case for sets of folded pixels that "see" similar coil pattern characteristics, i.e., "where the system of equations is ill-conditioned" or "where the geometry factor is high". Regularization can help significantly. This is particularly the case if that regularization is guided by a-priori knowledge.

In the case of Cartesian SENSE [1], the SENSE-part of the reconstruction consists of "unfolding" a set of folded points. The data has been acquired with *m* different coil elements. Each coil element has a different sensitivity-pattern, and "sees" the folded points with a different weighting, $m_i=\text{sum}_j(s_{ij}p_j)$, where p_j is the *j*-th of the folding points, s_{ij} is the sensitivity of coil element *i* at that point, and m_i is the data of coil element *i* before unfolding. In matrix notation, $\overline{m} = S\overline{p}$. Reconstruction has to determine $\overline{p}$ from $\overline{m}$.

Problem

The most straightforward way to solve this set of equations is to use the pseudoinverse [1]. Neglecting the noise-covariance for simplicity, this is written as: $\hat{\overline{p}} = (S^h S)^{-1} S^h \overline{m}$, where *h* indicates hermitian conjugate. The problem arises where the matrix $(S^h S)$ is badly conditioned: noise-enhancement is the consequence.

This issue has been addressed by regularization, e.g. [2]. This can be written as $\hat{\overline{p}} = (S^h S + \lambda I)^{-1} S^h \overline{m}$, where *I* is the identity matrix and λ is a tunable constant. This form is called zeroth-order regularization. Yet, by setting λ to a low value, the regularization is ineffective, while a too high value of λ leads to unfolding errors [2].

Method

In our approach, the regularization matrix is not constant over the image, but is derived from *a-priori* knowledge on the presence of tissue. That information is extracted from a low-resolution proton-density weighted reference scan, acquired with the quad body coil (QBC). That scan is available anyway whenever SENSE (or CLEAR) is used, for the determination of coil sensitivities.

The reconstruction can be written as $\hat{\overline{p}} = (S^h S + R^{-1})^{-1} S^h \overline{m}$, where R is a diagonal matrix. Each diagonal element thereof corresponds to a location *j*, and the diagonal values of R are proportional to the square of the QBC calibration-scan at that location.

Note that this approach is *feed forward*, in the sense that $(S^h S + R^{-1})^{-1} S^h$ can be calculated *before* the actual scan takes place. This allows a faster reconstruction than if R is to be determined by an iterative procedure (as in [3]).

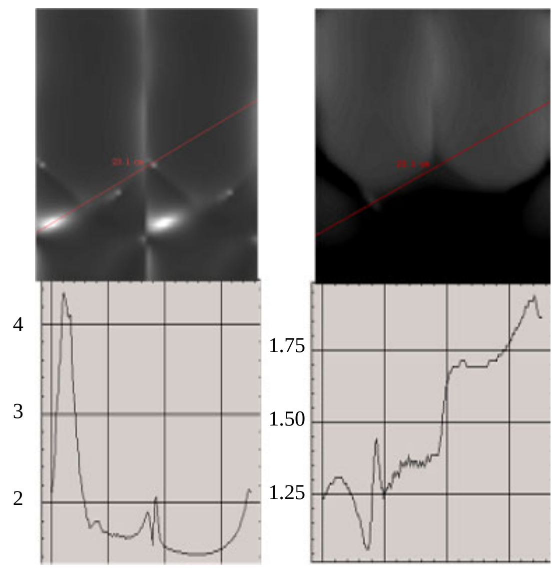

Figure 1: geometry factor images/plots with/without regularization

Discussion

Figure 1 shows a geometry-factor image (SENSE-factor=2) of a sagittal view of a human head. Without regularization, the geometry factor locally peaks up to a value of 4.

In effect, this approach locally reduces the SENSE-factor. Whenever points are to be unfolded where one or more of them are clearly outside the object, then the set of SENSE-equations, effectively, reduces to the remaining points. This benefit is particularly important if SENSE is applied in both phase-encoding directions simultaneously. Even if the encoded region exactly spans the object size, natural objects tend to leave some "room" to reduce the actual SENSE factor. This is illustrated in figure 2.

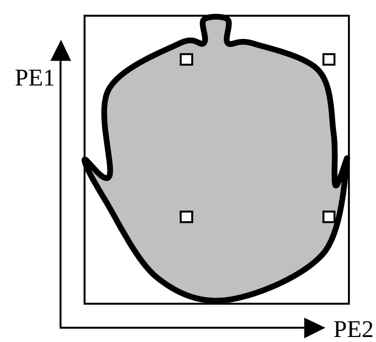

Fig.2. Example of a 3D-scan with SENSE in a head. Two phase-encoding directions are shown. The total SENSE-factor is 4. Yet, in most cases, one of the four points effectively falls outside the head.

Conclusion

The availability of QBC reference data, containing a-priori information on tissue-presence, allows to reduce the geometry factor in SENSE reconstructions.

References:

[1] K. P. Pruessmann *et al.*, Mag. Res. Med. 42, p. 952 (1999)
[2] K. F. King, L. Angelos, ISMRM 2001, p. 1771
[3] J. Tsao *et al.*, ISMRM 2003, p. 484