Minimal Artifact Factor SENSE

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Introduction

In this work, an extension of the SENSE parallel imaging framework is proposed. In the well-known SENSE solution [1], the reconstruction inversion problem is optimized to get the highest signal-to-noise ratio (SNR) in the image. In the new framework called Minimal Artifact Factor SENSE (MAF-SENSE), also artifact probability due to incorrect knowledge of the receiver coil sensitivities is taken into account. The latter is realized by adding an uncertainty in this knowledge in order to enable weighting of residual artifact level and SNR in the inversion problem.

Methods

Within the SENSE framework it is demonstrated that with correct knowledge of the receiver coil sensitivities and only measurement noise being present, the optimal reconstruction is shown to be:

$$\mathbf{p} = \left(\mathbf{S}^{\mathbf{h}}\boldsymbol{\psi}_{\mathbf{n}}^{-1}\mathbf{S}\right)^{-1}\mathbf{S}^{\mathbf{h}}\boldsymbol{\psi}_{\mathbf{n}}^{-1}\mathbf{m} = \mathbf{Hm} \quad (1)$$

With **p** a vector containing the reconstructed pixels of length equal to the SENSE factor, **S** the receiver coil sensitivity matrix, $\boldsymbol{\psi}_{\mathbf{n}}$ the noise covariance matrix and **m** a vector with the measured data of each coil element after Fourier transform. Now, it is assumed that the coil sensitivities also contain some error. To be more precise, it is assumed that the error is proportional to coil sensitivity with proportionality constant σ_s. Giving this model, a coil sensitivity error covariance matrix can be determined $\boldsymbol{\psi}_{\mathbf{a[j]}}$, with a standing for artifact and [j] denoting that this matrix differs per reconstructed pixel *j*. The individual elements of this diagonal matrix are calculated as:

$$\psi_{\mathrm{a[j]}kk} = \sigma_n^2\sigma_s^2\left(\sum_i\left(\|s_{ki}\|^2\right) - \|s_{kj}\|^2\right) \quad (2)$$

With σ_n the SNR of the calibration scan to determine the coil sensitivities and the subscript *i* denoting the locations that fold back on location *j*. σ_n is introduced to assure that $\boldsymbol{\psi}_{\mathbf{a[j]}}$ is in the same order of magnitude as $\boldsymbol{\psi}_{\mathbf{n}}$. Now the MAF-SENSE equation can be rewritten as $p_j = \left(\mathbf{S}^{\mathbf{h}}\boldsymbol{\psi}_{[\mathbf{j}]}^{-1}\mathbf{S}\right)^{-1}\mathbf{S}^{\mathbf{h}}\boldsymbol{\psi}_{[\mathbf{j}]}^{-1}\mathbf{m}$, with $\boldsymbol{\psi}_{[\mathbf{j}]} = \boldsymbol{\psi}_{\mathbf{n}} + \boldsymbol{\psi}_{\mathbf{a[j]}}$. In such a way, the combination of SNR optimization by means of ψ_{n} and artifact reduction by means of $\psi_{\mathrm{a[j]}}$ is realized in the MAF-SENSE solution. Depending on the assumed values of coil sensitivity uncertainty, SNR and artifact level can be weighted in the optimization criterion.

Volunteer experiments were done on a 3T system (Ingenia, Philips Healthcare, Best, The Netherlands). Transverse single shot T2-weighted TSE scans were performed on the liver of 2 volunteers, after which SENSE and MAF-SENSE reconstructions were made. The scan parameters were: FOV 375x300 mm, matrix 268x184, 25 slices with thickness 6 mm and gap 1mm, TE/TR 80/1200, SENSE factor 3, 28 receiver coil elements. The sensitivity maps were measured with a 3D gradient echo calibration scan. In order to obtain a mismatch between the calibration and the SENSE scan, and thus incorrect coil sensitivities, an inspiration breath-hold instruction was given for the calibration scans and an expiration instruction for the SENSE scans. MAF-SENSE reconstructions with different values for σ_s were performed. Artifact levels were calculated by drawing an ROI over the artifact and an ROI over the same tissue without artifact. The artifact level was quantified as the relative signal difference between those two ROI's.

Results

Figure 1a shows an image of a normal SENSE reconstruction with the 2 ROI's used for artifact quantification. The smallest ROI is over the artifact. In figure 1b, the MAF-SENSE reconstruction with $\sigma_s = 0.30$ is depicted. In this image, the SENSE artifacts are not visible anymore. In figure 1c, the artifact level as function of σ_s is rendered. This demonstrates the capability of MAF-SENSE to reduce SENSE unfolding artifacts.

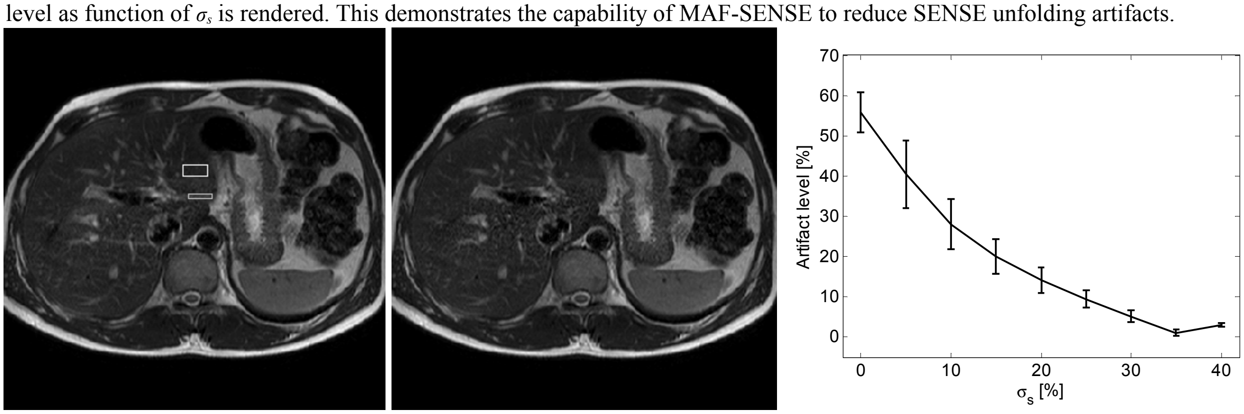

Figure 1a: Normal SENSE reconstruction with the small ROI over the SENSE artifact in the liver and the large ROI pointing at the reference region without artifact, b: MAF-SENSE reconstruction with $\sigma_s = 0.3$, c: SENSE artifact level as function of σ_s.

Conclusions

We have shown a new parallel imaging reconstruction technique that builds on the well-known SENSE technology. With MAF-SENSE, the SENSE unfolding and channel combination does not only focus on SNR optimization alone, but also artifact levels due to incorrect coil sensitivities are weighted in the optimization procedure. MAF-SENSE is well capable of artifact reduction compared to the SNR optimized standard SENSE solution, but a penalty in SNR is paid.

Reference Pruessmann, KP, et al., MRM 42:952-962(1999)

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