Optimized RX Field Homogeneity for SENSE Imaging in Parallel Transmit MR

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Introduction

In high-field MRI (≥ 3T), the RF field homogeneity is reduced due to the dielectric properties of the patient. The inhomogeneity of the transmit (TX) field can lead to spatial variations in image contrast and intensity, which can be compensated by parallel transmission using RF shimming [1] and related techniques [2,3]. On the other hand, the reception (RX) field inhomogeneity can also lead to intensity variations. This is especially important in SENSE applications [4], where image intensity directly scales with the intensity of the body coil reference image. Most parallel transmit arrays can also be used as RX arrays, which offers new possibilities in the reconstruction of the reference image. This study applies this degree of freedom to improve the homogeneity of SENSE images. Different reconstruction approaches are investigated and an optimization solution similar to transmit RF shimming is proposed.

Methods

A body coil with 8 TX/RX channels [5] was used in a 3T MR scanner (Philips Healthcare, Best, The Netherlands). The 8 TX-elements of the body coil are designed as relatively large TEM elements (420mm x 100mm), arranged circularly around the patient.

For the SENSE reference scan, 3D gradient-echo images were acquired with the multi-channel body coil and a 16-channel surface array (TR/TE = 4.0/0.6 ms, α=1°, resolution 7.5x7.5x15 mm^3). The actual SENSE scans were acquired using the surface array only (TR/TE = 4.6/2.3 ms; α = 15°, resolution 1.4 x 1.4 x 5 mm^3, reduction factor R=2). All scans were acquired with RF shimming to achieve an optimized TX-field homogeneity.

In RF shimming, TX-field homogeneity is improved by a patient-specific superposition of the TX-fields of the individual channels. This is however limited to a global optimization of the relative amplitudes and phases of each TX channel. On the receive side, the signals from the individual RX channels can be combined voxel-by-voxel in the image domain. This allows using a magnitude combination and hence constructive signal combination, independent of the signal phases. This advantage was used for the reconstruction of a homogeneous body coil reference image. For comparison, the following different reconstructions were carried out: a) a complex-valued image combination to mimic a single-channel birdcage coil, b) sum-of-squares combination (SOS), c) sum-of-magnitude combination (SOM), and d) a weighted sum-of-magnitude combination (wSOM). The latter is a generalization of the SOM combination according to Eq. (1), where the w_i denote some weights. Optimal weights were calculated according to the least-squares approach in Eq. (2), where c is a constant that is used to maintain the average image intensity and λ is a regularization parameter. For large λ, this gives w_i=1, which is identical to SOM. As a region of interest, all non-background voxels in the SENSE scan volume were used.

$$I_{ref}(x) = \Sigma_i w_i |I_i(x)| \quad (1)$$

$$\hat{w}_i = \arg\min \left(||\Sigma_i w_i |I_i(x)| - c||_2^2 + \lambda \Sigma_i (w_i - 1)^2 \right) \quad (2)$$

Results and Discussion

The body coil reference images using the different reconstructions are compared in Fig. 1 (top row). The corresponding SENSE scans are shown below. a) The complex-valued combination of the body coil images can lead to an interference pattern, with darkening in the area of the spine and a very bright center as often observed in birdcage coils. b) The SOS reconstruction gives a more homogeneous RX-field, but appears unfavorably dark in the center of the body. c) The SOM combination results in an acceptable homogeneity. d) The introduction of weighting factors (wSOM) can further improve image homogeneity, e.g. by compensating the differences in the coil load factors.

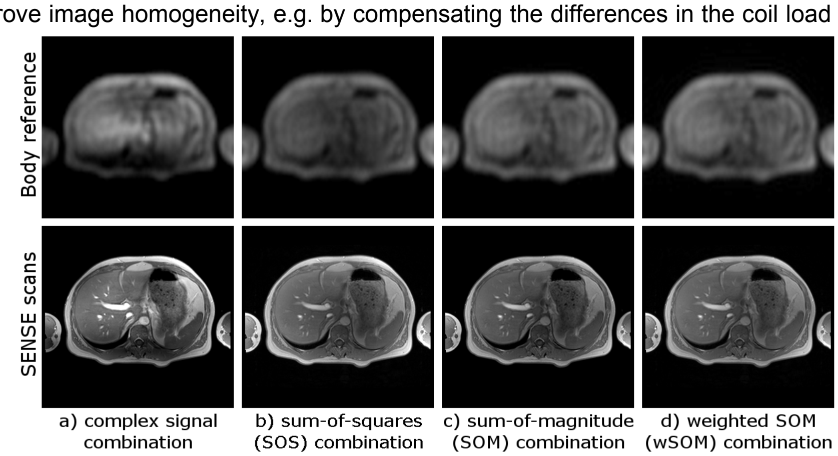

Fig. 1: Different reconstructions of the body coil reference scan (top row). The corresponding SENSE scans show the same shading pattern (below).

Conclusions

Parallel transmission with a multi-channel body coil offers a new degree of freedom in the reconstruction of the body coil reference image. This was successfully applied to improve image homogeneity of SENSE scans.

The interference pattern observed in SENSE images at high field strengths can be partially compensated by magnitude combination of the body coil reference image. Whereas a SOS reconstruction is optimal with respect to the SNR [6], this is not a requirement in the SENSE reference scan, while superior homogeneity can be achieved by the SOM combination. By introducing weighting factors (wSOM) further improvement of the homogeneity is feasible in analogy to transmit RF shimming.

When complex valued sensitivity maps are required, e.g. for chemical-shift encoding, a phase-reference from the complex reconstruction could be added to the magnitude-combined images. The approach discussed for a multi-channel TX/RX body coil here might also be applied for surface transmit arrays if no body coil is available.

References

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