Wave-propagation based estimation of coil sensitivities

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Introduction

The knowledge of accurate sensitivity maps is important for massively parallel MRI [1,2] to create artifact-free images. However, acquiring a low-resolution reference scan and dividing coil element data by the body coil reference as gold standard leads to two opposed problems. On one hand, the low resolution of the reference scan cannot cope with steep sensitivity changes, which leads to a misestimate of the sensitivity close to the coil elements. On the other hand, the obtained coil sensitivity is not stable in regions with a low signal level. To overcome this problem and to optimize the sensitivity maps, interpolation and extrapolation methods [3-5] have been described. This abstract presents an alternative approach to estimate the coil sensitivities, taking the basic coil geometry and the wave propagation in an arbitrary homogeneous medium into account.

Methods

The approach is also based on a low-resolution reference scan, where a sensitivity estimation is performed for each receive coil element independently. Only voxels of the reference scan with a reasonably high signal level in both, body coil reference and coil elements, are taken into account for a stable basis. At these points, the magnetic field is simulated for the known coil geometry using a wave propagation model with homogeneous object properties, based on the Maxwell's equations. An optimization process compares the calculated and the measured field and minimizes the standard deviation automatically by adjusting the electrical properties of the object and the position/orientation of the coil, using the maximum coil signal as the starting point. The resulting parameter set (position, angulation, current, ε, σ) allows the calculation of the coil sensitivity at any arbitrary point. The optimization was implemented using a rather inefficient, but reliable simplex algorithm [6] showing a sufficient convergence for the first experiments.

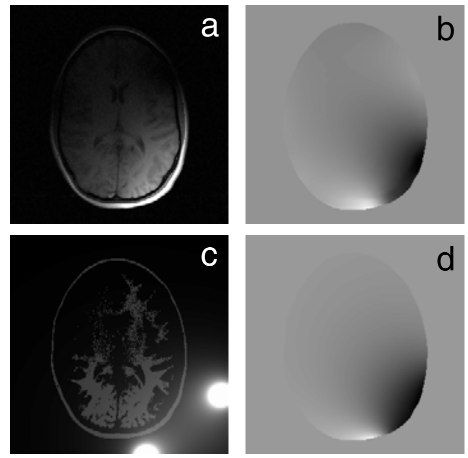

Fig. 1: Sensitivity estimation of a six-element head coil. The sensitivity of one coil element (a) is measured, whose real part is shown in (b). This reference is used for the sensitivity estimation, which is presented together with the head position in (c), the cropped real part is given in (d).

Results

The approach was tested on different receive coil setups on a 1.5T ACHIEVA clinical scanner (Philips Medical Systems). Fig. 1 demonstrates the sensitivity estimation of a six-element head coil, where Fig. 1(a) shows a high-resolution anatomical image of one coil element. The measured coil sensitivity (real part given in Fig. 1(b)) serves as basis for the proposed sensitivity estimation. Its result is shown in Fig. 1(c) with the head geometry superimposed. The real part inside the head is displayed in Fig. 1(d) for comparison.

To test the "SENSEability" of the approach, the coil sensitivities of a 32 element cardiac array were estimated in-vivo on healthy volunteers. First, a 3D reference scan with a voxel size of $11\times15\times15mm^3$ was performed. The estimated sensitivities were used for the reconstruction of a respiratory gated, fat-suppressed, 3D whole-heart coronary scan. A FOV of $256x256x135mm^3$ was acquired with a voxel size $1.33\times1.33\times1.5mm^3$ and a reduction factor of 4 (2×2, FH×AP). Fig. 2 compares the different reconstructions using the same acquired data, but different coil sensitivities. The slice shown in Fig. 2(a) is reconstructed with the "gold standard" sensitivities, while Fig. 2(b) uses the fitted coil sensitivities. Both images show a high image quality, however Fig. 2(b) seems to be a bit more stable and homogeneous. Fig. 2(c) and Fig 2(d) show the geometry factors corresponding to Fig. 2(a) and Fig 2(b) respectively, with rather similar values, while the instability of the g-factor in Fig. 2(c) points to the utilization of a bit unstable coil sensitivities.

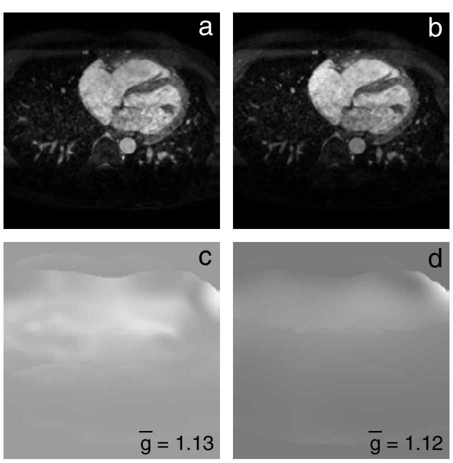

Fig. 2: 2×2-SENSE reconstructions using different coil sensitivities. One transversal slice of 3D dataset is shown, reconstructed with the standard sensitivities in (a), while (b) shows the reconstruction using the fitted coil sensitivities. The corresponding geometry factor distributions are shown in (c) and (d) respectively.

Discussion

The results for different receiving coils and several in-vivo studies demonstrate that the coil sensitivities can be estimated rather robustly with the presented approach. Only previously known information, namely the basic geometry of a coil element, is used together with a standard low-resolution reference scan. Its advantage, compared to the gold standard, is the availability of an accurate and stable coil sensitivity estimation in the whole FOV, including areas outside the human body or areas inside with a very low signal level. This holds especially for the region close to the coil element, where the standard approach may introduce image artifacts, which is a problem of inter- or extrapolation methods [3-5], too. The robust behavior of the presented approach, as only a few unknowns have to be estimated, may reduce the number of averages needed in the reference scan and hence significantly reduce its scan duration. Even if no body coil reference is available, a sensitivity estimation based on low resolution coil data can be performed. The calculation took about 1-2 minutes for each coil element, but is supposed to be easily reduced to a few seconds, hence may not affect a scanning session noticeably. Coupling issues of neighboring coil elements were negligible for the applied coils. If this is not the case, additional coupling parameters have to be taken into account. The general structure of the sensitivity estimation does not need any information about the measured object, whose electrical properties are estimated as global parameters during the fitting. This approach may be further optimized using information about the spatial distribution of these parameters, potentially obtained from the reference scan.

Conclusion

The estimation of the coil sensitivities using a wave propagation model is presented. First in-vivo studies on different anatomies suggest a high potential of the approach and demonstrate a robust behavior. The availability of a stable coil sensitivity at any position with an affordable calculation effort allows the reconstruction of artifact-free, high quality and highly SENSE accelerated images.

References

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