Residual aliasing removal in higher order SENSE

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Introduction

The performance of parallel imaging [1,2,3] is continuously increasing and allows for higher reduction factors supported by appropriate receive coil arrays. However, high reduction factors may lead to residual aliasing in SENSE [2] reconstructed images due to an imperfect estimation of the local coil sensitivity profiles. This work shows a possibility to reduce this aliasing artifact. A coil sensitivity mismatch can be identified and corrected by using the redundancy in the acquired data. The following abstract outlines the basic approach and is a proof of principle.

Methods

The well-known SENSE reconstruction problem is given in Eq. (1), where the c_n represent the coil signals, ρ_r the voxels to be unfolded and S_{nr} the corresponding sensitivity profiles. In general, the number of receive coil elements N is larger than the reduction factor R in parallel imaging, which means that the reconstruction is over-determined with a certain redundancy in the data.

$$\begin{pmatrix} c_1 \\ c_2 \\ \dots \\ c_n \end{pmatrix} = \begin{pmatrix} S_{11} & S_{1r} \\ S_{21} & S_{2r} \\ \dots & \dots \\ S_{n1} & S_{nr} \end{pmatrix} \begin{pmatrix} \rho_1 \\ \dots \\ \rho_r \end{pmatrix} \quad (1)$$

This allows to check the quality of the reconstruction and furthermore, to correct for possible errors. A statistical analysis, using the χ^2-deviation [4] of the SENSE reconstruction, compares the individual folded coil images with the back-projection of the SENSE reconstructed image and identifies defective voxels. In the current analysis, it is assumed that this inconsistency is caused by errors in the pre-measured coil sensitivities. Thus, if an error is identified, the corrupt element S_{ij} in the sensitivity matrix has to be detected first. The affected row in S_{nr} is determined by choosing the coil signal with a maximum contribution to the χ^2-deviation. Within this row, the maximum sensitivity value is considered to be defective, as a wrong estimate for the coil sensitivity most probably occurs in areas close to the coil, where the low-resolution reference scan is not able to capture steep sensitivity changes.

After localizing the defective sensitivity element, an additional SENSE reconstruction is performed with a reduced unfolding matrix, excluding the identified row in S_{nr}. The result is used to calculate an estimate for the defective sensitivity matrix element. A corrected sensitivity element is defined by relaxation, taking the old and the new value into account. This procedure is embedded in an iterative loop, terminated, if the χ^2-deviation is at a sufficiently low level.

Results

This approach was tested on a 1.5T ACHIEVA system (Philips Medical Systems) equipped with 32 receive channels. A phantom study was performed, as in-vivo data tend to smoothen those kinds of artifacts. An image of a cylindrical phantom (Fig.1(a)) was acquired with a resolution of $0.8\times0.8\text{mm}^2$ (512×512 matrix size) and a reduction factor of two, using a 32 channel abdominal array, consisting of two 4×4 sections (top and bottom). The reference scan had a high resolution ($6\times6\text{mm}^2$), while the sensitivities of two neighboring coils were strongly low-pass filtered as shown in Fig.1(b). Fig.1(c) demonstrates the residual ghosting in the SENSE image, which was identified and removed by the presented approach in Fig1(e). Fig.1(d) shows the corrected coil sensitivity without any further processing.

Discussion / Conclusion

The redundancy in parallel imaging is generally used to maximize the SNR. Besides that, it can additionally serve as the basis for further image corrections. In this work, the coil sensitivities were corrected in areas, where an inconsistency in the data was identified. The iterative approach exhibits a certain calculation effort (a few seconds for the presented example), but has also some strong points: If several coils have a sensitivity mismatch in a voxel, the algorithm is able to correct all affected sensitivities by addressing different coils in the individual iteration steps. Furthermore, no information is excluded from the reconstruction, as the profiles are adjusted and not excluded. Thus, the maximum SNR can be retained, and the corrected coil sensitivity can be used for subsequent scans. This might be of interest in dynamic studies like functional brain MRI. Of course, the presented example shows a very high redundancy to facilitate the correction. Nevertheless, this simulation represents a more or less realistic case, as a typical sensitivity error occurs at the edges of an object, close to a coil element, which exhibits its maximum sensitivity in this region. For this reason, we consider a correction of the coil sensitivity as very useful, whereas the exclusion of this coil from the reconstruction would result in a large waste in SNR. In the future, it may even become more important, as more and smaller coil elements will be used to allow high reduction factors, which conflicts with the low resolution of the reference scan.

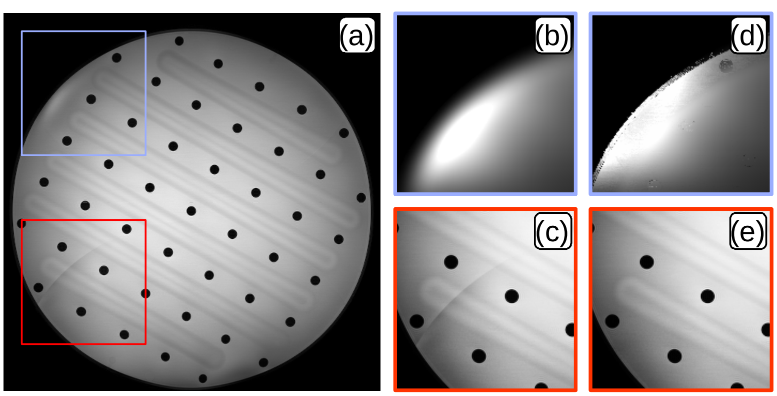

Fig.1: Demonstration of the sensitivity correction. The sensitivity profiles of two neighbored coils are subsequently low-pass filtered (b), which leads to a ghosting in PE-direction (a,c). The coil sensitivity after the correction without any post-processing is shown in (d) while the previously disturbed area shows a complete removal of the residual aliasing in (e).

References

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