Artifact removal using a parallel imaging approach

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INTRODUCTION:

MR imaging using several receive coils in parallel exhibits in general some redundancy in the acquired data. This redundancy or over-determination has been used recently to check data conformance and perform appropriate corrections in the k-space domain [1]. In contrast to this method, the here presented approach removes ghost-type artifacts in the image domain using a modified SENSE reconstruction.

THEORY:

Ghost artifacts are spurious signals caused by motion or flow as well as chemical shift. They appear at a certain location r_0 in the image, which differs from their origin *r'*. However, the level of such an artifact in a single coil image is given by the coil sensitivity of its origin *r'*. Thus, a voxel disturbed by a ghost leads to the signals $\vec{c}$ received by the different coils:

$$\vec{c} = S\vec{\rho} + S'\vec{\delta} \qquad (1)$$

where $\vec{\rho}$ denotes the spin densities and *S* its sensitivity weights. The superimposed artifact $\vec{\delta}$ is weighted by the sensitivities *S'* according to its spatial origin *r'*. Combining *S* and *S'* to an enlarged matrix S^e and calculating its pseudo-inverse allows the separation of $\vec{\rho}$ and $\vec{\delta}$. However, the redundancy for this voxel-wise correction must be sufficient to avoid an under-determination in the calculation of S^e.

METHODS:

The presented method performs an ordinary SENSE reconstruction [2] for each voxel of the coil images and checks its conformance with a normalized χ^2-test using the incomplete gamma function *Q* [3]. A systematic error is considered in voxels with low *Q*, where the "extended SENSE" reconstruction with S^e is triggered. However, the location of the artifact origin *r'* is unknown. This is found iteratively by calculating the χ^2-deviation of the extended reconstruction and using the sensitivities *S'* of different *r'*. The χ^2-deviation shows a minimum for the true *r'*, which ensures a maximum separation of $\vec{\delta}$. (see Fig.1). To reduce the calculation effort, *r'* is supposed to be located along the phase encoding direction. A problem is related to the inversion of S^e: As its rank increases, S^e may become ill-conditioned resulting in noise amplification similar to the geometry factor g in SENSE [2].

The approach has been tested in phantoms as well as in cardiac and abdominal in-vivo applications.

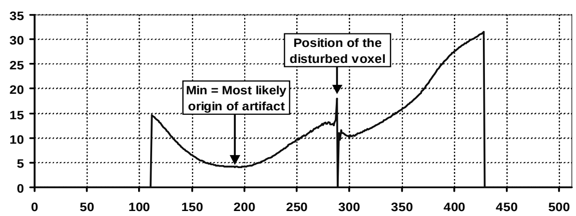

Figure 1: Artifact origin localization. The χ^2-deviation of the extended SENSE reconstruction shows a minimum for the optimal artifact origin *r'*. S^e becomes singular if $r' = r_0$.

RESULTS:

Cardiac images obtained on a 1.5T scanner (Philips Medical Systems), using a five element array and a gated SSFP-sequence (voxel size: 1.0x1.0x8 mm^3, TR/TE/FA: 5.0/2.5/60), are shown in Fig.2. Ghost artifacts are reduced applying the extended SENSE reconstruction.

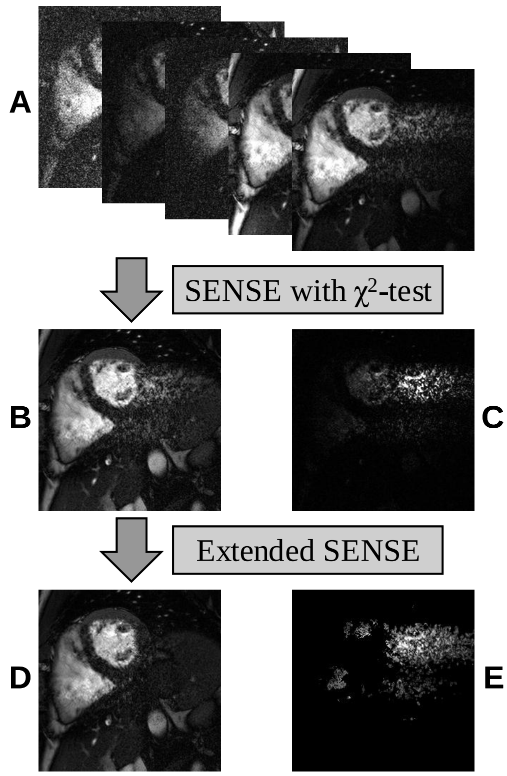

Figure 2: Extended SENSE reconstruction. The single coil images (A) form the basis for a first SENSE reconstruction (B), which is checked using the Q - function (C). Extended SENSE is only applied to voxels with a low Q (bright area in (C)) and if a moderate g can be ensured. (D) demonstrates the final result, while (E) shows the separated ghost artifact.

DISCUSSION:

Compared to a simple sum of squares combination, a SENSE or phased-array reconstruction [4] already reduces the ghost intensity [5], while the presented "extended SENSE" reconstruction allows to remove the artifact almost completely. It is only applied to disturbed voxels, whereas a tradeoff between removal and noise amplification avoids a loss in image quality. The reconstruction method does not affect the scanning procedure, and therefore represents a useful tool for several parallel imaging sequences.

REFERENCES:

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