Adaptive Coil Combination Using a Body Coil Scan as Phase Reference

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Target Audience: Researchers working with image reconstruction from multi-channel coils

Purpose: Combining images from multi-channel coils has always been a challenging task. The standard technique for this is "sum of squares" (SOS), which is near-optimal only in areas with sufficient signal-to-noise ratio (SNR). Also, the phase information is lost during reconstruction. Roemer et al.[1] showed that optimal complex reconstruction can be done when the relative complex sensitivities of the individual coils are known. Walsh et al.[2] proposed an adaptive technique where relative coil sensitivities are estimated directly from the multi-channel complex images. This technique is optimal from the point of view of SNR, and the phase is preserved. The problem is a missing absolute reference for the phase, which can result in phase singularities (points where the phase cannot be unwrapped). These present a problem for phase-sensitive techniques, and there may be signal dropouts. To overcome this problem, several techniques have been proposed, e.g.[3], but some restrictions may remain for calculations only from the image data. It is possible to acquire "absolute" complex coil sensitivities relative to the system's body coil in a separate acquisition, and use them for coil combination, e.g.[4,5]. However, there may be motion between the two acquisitions, or insufficient resolution, which may lead to different artifacts. Our technique combines this prescan approach with adaptive coil combination: low-resolution estimates of the coil sensitivities relative to the system's body coil are derived from the calibration scan, but are used for phase correction only, followed by adaptive coil combination with sensitivity estimation directly from the image data.

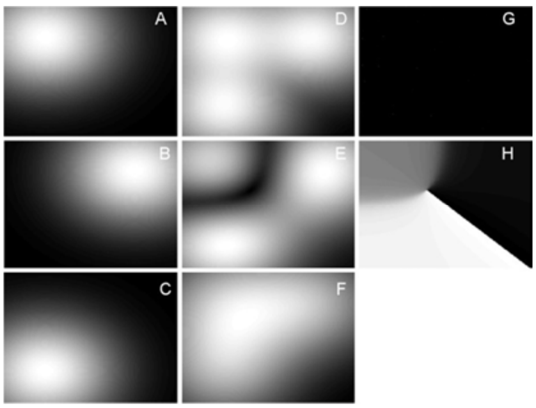

Fig. 1: Origin of phase singularities: A-H: see text.

Methods: Fig. 1 illustrates the origin of phase singularities: A, B, and C are magnitudes of synthetic sensitivities for three coils. D is the magnitude of the linear sum A+B+C if their phase is zero; the corresponding phase of the combined sensitivity G is zero, too. E is the linear sum of A+B+C when their phase is chosen constant but non-zero, e.g. 0, $-0.9\cdot\pi$, and $+0.9\cdot\pi$, respectively. The phase of this combined sensitivity H exhibits a phase singularity. Note that the location of the phase singularity coincides with zero magnitude of the combined sensitivity E. F shows the combined sensitivity after adaptive coil combination (which is the same as SOS combination in the absence of noise); the corresponding phase is also equal to H, if no other phase reference is used. Simple approaches to remove the phase singularity aim at removing a constant phase offset (in this case 0, $-0.9\cdot\pi$ and $+0.9\cdot\pi$, which in this case indeed removes the phase singularity). The constant phase offset can be estimated from the images themselves, or from some sort of navigator scan. However, all these estimates can fail in practice if the phase of the coil sensitivities is complicated, e.g. for high density coils.

Here, we use an additional low-resolution calibration measurement: 3D gradient echo with TR=2ms, TE=0.7ms, matrix size 32x32x64, with elliptical scanning and maximum field of view, scan time approx. 5s. This measurement is done with both the surface coils and the system's body coil, and it is normally used by the system for image homogeneity improvement. The coil sensitivity phase's spatial distributions relative to the body coil phase are calculated for all surface coils. These phase distributions are subtracted from the phases of the single channel complex images prior to adaptive coil combination. This modified algorithm was tested on a range of in-vivo data sets acquired on both 1.5T and 3T, from different body regions, using different coil arrangements, pulse sequences, and contrast mechanisms.

Results and Discussion: Image quality was found to be generally equal or better with phase correction than without phase correction; signal dropouts were successfully removed. Fig. 2 shows an example comparison of adaptive coil combination with and without phase correction, acquired at 3T (MAGNETOM Skyra, Siemens Healthcare, Erlangen, Germany) using a 16-channel head matrix coil. Images on the left side correspond to the phase after adaptive coil combination calculated directly from data, and with an arbitrary single channel as phase reference for the relative sensitivities. Images on the right side were calculated from the same data, but with added phase correction from the sensitivity reference scan. Benign phase behaviour is visible in the result. Not only were phase singularities and related problems removed, but the phase is also well suited for techniques like temperature mapping, quantitative susceptibility mapping, and other phase-sensitive methods.

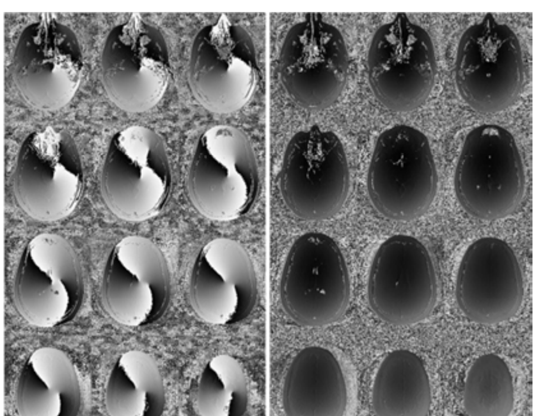

Fig. 2: Example comparison of head phase images with original (left) and new (right) adaptive coil combination

Relative sensitivity maps from the reference scan can also be directly used for image reconstruction, but problems can occur if the resolution of the calibration scan is too low to represent the sensitivities of highly localized coils, or if the coil positions have changed between calibration and imaging measurements. For purposes of phase correction, the phase map from the calibration scan may have inaccuracies, since its main purpose is to prevent phase singularities. The exact sensitivity estimate for the coil combination is done by the adaptive coil combination algorithm.

Phase difference methods without a volume coil as a reference have been proposed[6], and may also be useful for combination with adaptive coil combination.

Conclusion: The proposed solution combines the advantages of prescan and image data based coil sensitivity estimation approaches for coil combination. It avoids signal dropouts in the magnitude images, and is particularly advantageous for phase-sensitive image reconstruction. It can also be used for measurements with non-smooth phase of the MR signal, e.g. for fat and water signal in opposite-phase condition, where other phase correction techniques may fail. The disadvantage of this technique is that it requires an additional calibration scan. This, however, may be of low resolution and short duration, and is usually acquired anyway for purposes of image homogeneity improvement, so the impact on workflow is rather low.

References:

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