Noise Reduction in Slice Encoding for Metal Artifact Correction Using Singular Value Decomposition

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Introduction: MRI near metallic implants is often limited by severe artifacts. To obtain distortion-free MR images near metallic implants, SEMAC (slice encoding for metal artifact correction) [1] extends a view-angle-titling (VAT) [2] spin echo sequence with additional z phase encoding to resolve metal artifacts. Figure 1 illustrates that metal artifacts are corrected by combining the 3D data resolved from multiple SEMAC-encoded slices. However, many of the resolved voxels contain only noise rather than signals, which degrades the signal-to-noise ratio (SNR) of the corrected images. Here we modify the SEMAC reconstruction to perform denoising using singular value decomposition (SVD) [3], to increase SNR significantly.

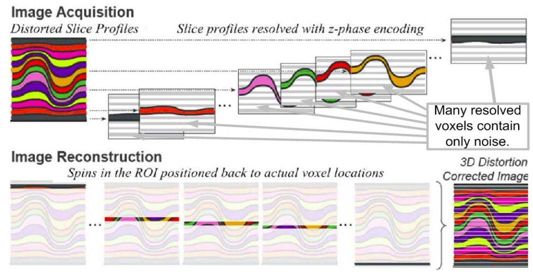

Fig. 1: SEMAC assigns the resolved data back to their actual locations, and combines the data to correct distortions. Note that many of the resolved data contain only noise.

Methods and Results: To correct metal-induced through-plane distortions, SEMAC performs 3D encoding of multiple slices such that the spins in the same voxel, but excited in different slices, can be placed back to their actual voxel locations and combined together. Thus, at each voxel (x,y,z), we have a vector $\boldsymbol{V}$ containing the signals that are resolved from multiple excited slices. The SVD-based denoising is based on the following observation: when the vector $\boldsymbol{V}$ is received by a coil, all the elements of $\boldsymbol{V}$ are subject to the same coil sensitivity, regardless of their frequencies.

Given the number of coils N, the vector received by the i^{th} coil is denoted as $\boldsymbol{V}_i = w_i \boldsymbol{V} + \boldsymbol{n}_i$, where w_i and $\boldsymbol{n}_i$ are the respective coil sensitivity and noise vector. We can form a matrix $\boldsymbol{M}$ whose i^{th} column is the signal vector $\boldsymbol{V}_i$. In the absence of the noise vectors, the rank of $\boldsymbol{M}$ is 1: all columns of $\boldsymbol{M}$ are the multiples of $\boldsymbol{V}$. Based on this observation, we can eliminate all noise orthogonal to the signal vector by truncating the singular values of $\boldsymbol{M}$ except the largest one (i.e., forming a rank-1 approximation of $\boldsymbol{M}$). By removing the orthogonal noise with the SVD-based denoising, the signals are less likely to be buried in noise. Subsequently, the correction of through-plane distortions includes only the signals whose magnitudes are greater than the empirically estimated background noise [4].

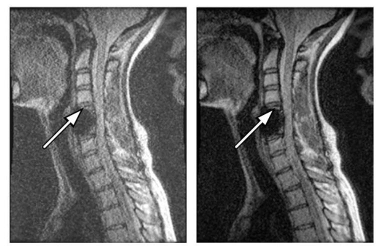

Fig.2: Comparison of the SEMAC-corrected images of a cervical spine obtained from (left) the existing SEMAC reconstruction and (right) the proposed SEMAC reconstruction.

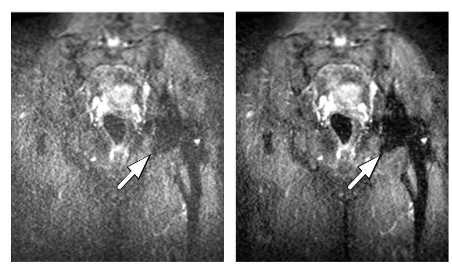

Fig. 3: Comparison of the SEMAC-corrected STIR images of a hip replacement from (left) the existing SEMAC reconstruction and (right) the proposed SEMAC reconstruction.

We scanned a subject with metallic implants in the cervical spine (Fig. 2) with an eight-channel head/neck phased-array coil and the following scan parameters: TE/TR=14/3751 msec with echo train length of 8, 256X192 matrix over 24 cm field-of-view (FOV). We also imaged a subject with total hip replacement using the SEMAC sequence incorporated with STIR (Short TI Inversion Recovery) [5] for fat suppression. An eight-channel cardiac phased-array coil and the following scan parameters were used: TE/TR=9.6/3820 msec with echo train length of 8, 256X192 matrix over 36 cm FOV. For both experiments, the SEMAC acquisition was accelerated with 2X ARC [6] parallel imaging and a partial Fourier ratio of 0.58 along the phase-encoding y axis. Fig 2 and 3 show the sample images; in each figure, the images are displayed with the same window level for comparison. The proposed technique significantly improves the SNR of the correction results such that the soft tissues near the metallic implants can be better visualized.

Discussion: SEMAC has shown great promise in obtaining distortion-free MR images near metallic implants. Nevertheless, the existing SEMAC reconstruction, which combines the data resolved from multiple slices, counteracts the SNR benefit brought by the long scan times associated with the additional z phase encoding. This work describes a new technique to reclaim the SNR loss in the SEMAC-corrected images. The efficacy of the proposed technique has been demonstrated in the clinical setting.

References:

[1] Lu W. et al MRM, 2009; 62(1):66-76. [2] Cho ZH. et al Med. Phys. 1998; 15:7-11. [3] Bydder M. et al MRI 2006; 24:849-56. [4] Lu W. et al ISMRM 2009; p 2781. [5] Bydder M. et al MRI 1985; 3:251-54. [6] Brau A. et al MRM. 2008; 59:382-95.

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