AMP-SENSE: PARALLEL IMAGING COMPRESSED SENSING WITH APPROXIMATE MESSAGE PASSING

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Introduction: Iterative Soft Thresholding (IST) and a more recent method, Approximate Message Passing (AMP) are promising techniques for fast compressed sensing (CS) reconstruction[1-3]. Combining CS, parallel imaging, partial-Fourier, and other techniques is still being investigated[4], and the reconstruction time is critical. The AMP method, as is currently implemented on a single coil basis, does not exploit known dependencies among coil images. We have developed a novel reconstruction method, AMP-SENSE, that incorporates coil sensitivity information into AMP to address the combined CS and parallel imaging problem, improving both performance and computational efficiency. We demonstrate an application to dynamic contrast-enhanced (DCE) breast MRI.

Methods: The AMP-SENSE algorithm applies AMP to the objective $\|y - Ex\|_2^2 + \lambda\|\Psi x\|_1$, where E is combined Fourier and coil-sensitivity-encoding of the image x, Ψ is the sparsifying transform, and y are the measurements from multiple coils. The objective includes coil-sensitivity information, which was estimated with the fully sampled central region and enforces data consistency for all of the coil measurements jointly while promoting sparsity of the underlying image. In the AMP algorithm (Fig. 1), the coil images are computed from an estimate of the image. The AMP residual is computed as $z^k = y - Ex^k + b^k z^{k-1}$, where the last term guarantees optimal nonlinear estimation at each iteration and weighting b^k is computed based on thresholding from the previous iteration, requiring negligible additional complexity[5]. Residuals are combined with the conjugated, normalized coil sensitivities. Following coil combination, sparsity (wavelet thresholding), support, and optional partial-Fourier constraints are sequentially applied to the image estimate. Without constraints and the AMP term, AMP-SENSE reduces to an existing parallel imaging method, POCS-SENSE[6].

To demonstrate the method, we reconstructed a resolution phantom with 4 groundtruth sensitivity maps (undersampling factor = 47) using POCS-SENSE, a single-coil AMP implementation, and AMP-SENSE. We also reconstructed a single echo from DCE breast MRI acquired using a 16-channel breast coil (Sentinelle Medical Systems, Toronto) using the DISCO pattern[7], as shown in Fig 2 (undersampling factor = 25, matrix size = 256x308x192), and included the reconstruction with L1 SPIRiT. All reconstructions were performed in Matlab (PC, dual 6-core Intel Xeon X5650 processors, 64 GB RAM) and intialized with the zero-filled k-space data. Depending on the constraints, the residual may not vanish, so we used a stopping criterion based on the residual change from the prior iteration.

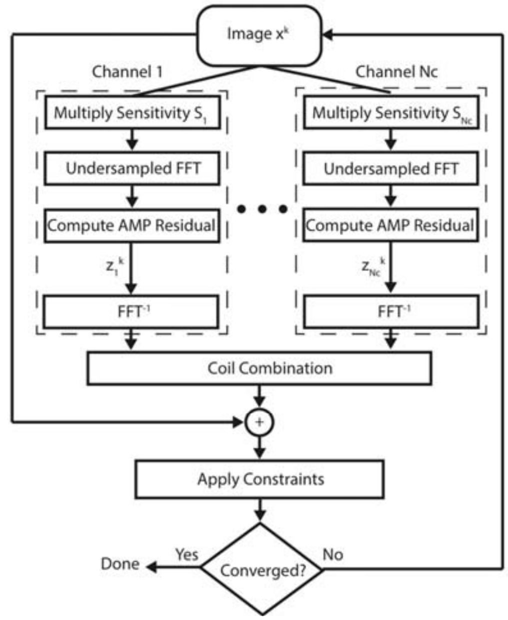

Figure 1: Proposed AMP-SENSE algorithm

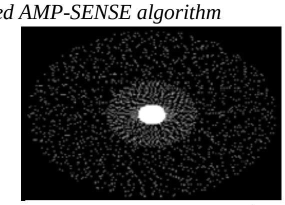

Figure 2: ky-kz sampling for breast DCE MRI

Results and Discussion: Figure 3 shows error images for the resolution phantom reconstruction. Neither CS nor parallel imaging alone recover the image without coherent artifacts. AMP-SENSE combines the advantages of CS and parallel imaging and shows error near the edges. Figure 4 shows the reconstructions for the breast. AMP-SENSE resolves coherent artifacts seen in POCS-SENSE (arrow) and single-coil AMP reconstruction and depicts features (arrow) that are not clearly visible in either single-coil AMP or parallel imaging reconstructions. The sampling pattern is designed to allow viewsharing and not for L1 SPIRiT, but the AMP-SENSE reconstruction may appear no worse than the L1 SPIRiT reconstruction. We omit viewsharing reconstructions and a discussion of temporal behavior for clarity.

Table 1 shows that the reconstruction time is significantly improved relative to single-coil AMP reconstruction, as our method requires only one forward and inverse wavelet transform per iteration instead of one for each coil image. If a large number of coils are used, FFT computations dominate the time to apply constraints to the combined image in AMP-SENSE, allowing compressed sensing to be included in the reconstruction with little additional complexity.

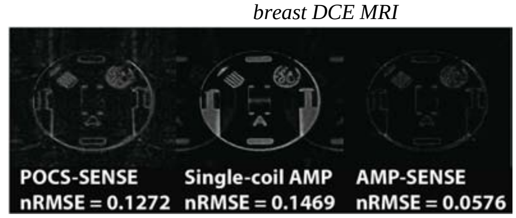

Figure 3: Resolution phantom reconstruction error

Method	Recon. Time	# Iterations
POCS-SENSE	8.75 min	13
Single-Coil AMP	142 min	7.6 per coil
AMP-SENSE	14 min	8

Table 1: Comparison of reconstruction time, breast DCE MRI (Matlab)

Conclusion: We have developed a novel reconstruction method, AMP-SENSE, that applies AMP to combined parallel imaging and CS. AMP-SENSE improves the computational efficiency and reconstruction performance of the AMP method. Its algorithmic simplicity and connection to POCS-SENSE suggest extensions for other constraints and techniques such as noncartesian imaging. We have demonstrated one application in DCE breast MRI, but it may be practical for any rapid imaging application employing combinations of CS, parallel imaging, and partial-Fourier.

References: [1] Anitori et al., IEEE Trans. Inf. Theory 2011; [2] Sung et al., MRM 2012; [3] Worters et al., JMRI 2012; [4] Liang et al., MRM 2009 62(6) [5] Donoho et al., PNAS, 2009; [6] Samsonov et al., MRM 2004 52(6); [7] Saranathan et al., JMRI 2012 **Acknowledgements:** Funding from NIH P41 EB015891, R01-EB009055, and GE Healthcare

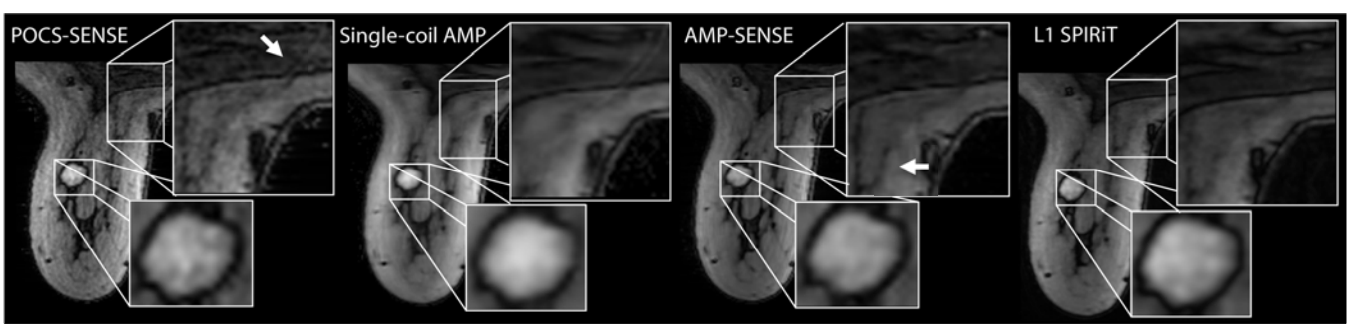

Figure 4: Breast DCE MRI reconstruction