Improving the achievable temporal resolution of compressed sensing in CE MRA

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Introduction Applying compressed sensing (CS) in contrast enhanced (CE) MRA exploits the intrinsic sparsity of contrast enhanced angiogram [1]. In time-resolved imaging such as HYPR, image prior knowledge from low temporal resolution data set is used to reconstruct images at a high temporal resolution [2]. We here introduce a Cartesian compressed sensing (CS) based method that exploits the composite image to achieve an acceleration factor level that is comparable to that offered by HYPR. Both the composite and time-resolved images are reconstructed from the same dataset, effectively allowing retrospective selection of acceleration factor.

Theory The success of CS recovery [1] in CE MRA is fundamentally limited by the sparsity of the angiogram to be recovered. We propose to incorporate a data sorting process (denoted as R) into CS reconstruction to rearrange the elements in the underlying image $\mathbf{f}$, so that it could be recovered in an alternative form $\mathbf{g}$ that features a higher level of sparsity that promises a better CS recovery. Then the final image estimate $\hat{\mathbf{f}}$ is obtained by applying an reverse sorting (denoted as R^{-1}) to the estimate $\hat{\mathbf{g}}$:

$$\mathbf{f} \xrightarrow{R} \mathbf{g}, \ \hat{\mathbf{g}} = \text{argmin}_{\mathbf{g}}(\| \mathbf{y} - W_R \mathbf{g} \|_2 + \alpha \| \Phi \mathbf{g} \|_1), \ \hat{\mathbf{g}} \xrightarrow{R^{-1}} \hat{\mathbf{f}} \quad (1)$$

where $\mathbf{y}$ and W_R respectively denotes the acquired data set and the Fourier encoding matrix whose columns are rearranged to reflect the sorting process R; Φ is the sparsifying transform used. The sorting order R is obtained from a composite image at a low temporal resolution.

The overall method is illustrated in Fig. 1, assuming the stationary anatomical background is eliminated. Firstly a sampling mask with a non-uniform sampling density is created, and then the samples within the sampling mask are sequentially acquired in a randomized order. A composite image is obtained using the acquired sample ensemble. Then a sorting order R is obtained by rearranging the elements in the composite image to form a monotonic variation (which is sparse under a wavelet transform) according to their intensity levels. This sorting order R is then applied in reconstructing temporal images at high temporal resolutions using Equ. (1), followed by the inverse sorting process R^{-1}.

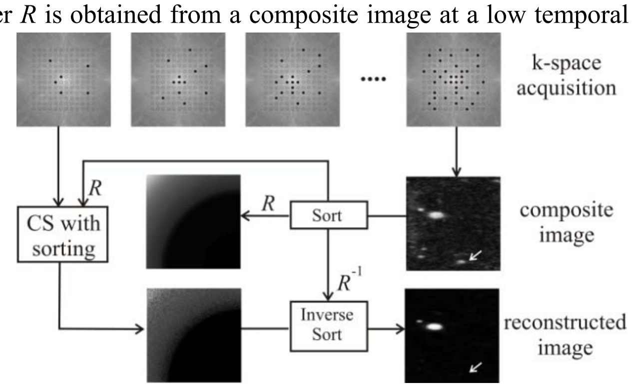

Figure 1 : overall procedure of the proposed method.

Method A coronal 3D scan (fast spoiled gradient echo) of the knee of a healthy volunteer was obtained using a 1.5T GE scanner equipped with an 8-channel receiver coil. 20ml of Gd-BOPTA (Multihance ®) was injected as a bolus. A matrix size of 256×128×48 was used to obtain a spatial resolution of 0.9×0.9×1mm. TR/TE = 5.4/1.6 ms, flip angle = 45°. A sampling mask at an acceleration factor of 4 was used. A k-space data set acquired without the presence of contrast was used for estimating the coil sensitivity profile and subtracted from the subsequent repetitions to suppress the stationary anatomical background.

Results and discussion Image reconstructions using conventional CS and the proposed method at various acceleration factors are compared in Fig. 2. The composite image (Fig. 2.a) corresponds to the entire data acquisition time interval that contains both arterial and venous phases, and was obtained by Fourier transforming the under-sampled k-space at acceleration factor of 4. Image reconstructions were made using k-space measurements acquired in the arterial phase. It is seen that at an acceleration factor of 12, both approaches led to reasonably good reconstructions; however at higher acceleration factors (24 and 36), the proposed method led to better reconstructions comparing to the conventional CS approach: vascular regions with low contrast are better recovered as indicated by the arrows, as a result of the improved image sparsity with a data sorting.

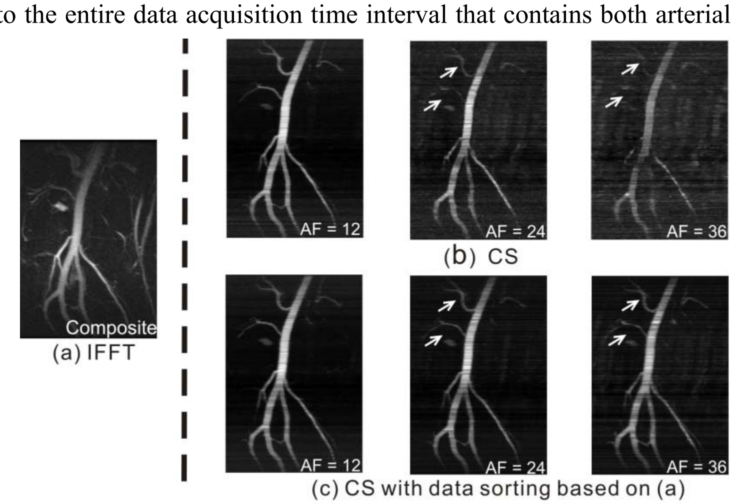

Figure 2: Reconstructed coronal MIP images using conventional CS (b) and CS with data sorting (c) at various acceleration factors (AF, as labeled in bottom corner). The composite image used for obtaining a sorting order is shown in (a).

Conclusion A new CS based method for CE MRA is introduced. It achieves substantially improved image recovery comparing to conventional CS approach by exploiting image prior knowledge embedded in a composite temporal data set via a data sorting. This has been demonstrated in image reconstructions with a true temporal resolution of less than 1s with sub-mm isotropic spatial resolution.

References
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[2] Mistretta CA, et al. MRM, 2006.