Accelerating Sparse Object Imaging by Simplified Skipped Phase Encoding and Edge Deghosting with Array Coil Enhancement (SPEED-ACE)

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Introduction

MRI scan can be accelerated by various fast imaging methods. Some of these methods take advantage of the unique nature of the data[1,2] such as sparsity. For sparse object imaging, e.g. MRA, the sparse signal distribution can be used to both simplify and further accelerate the parallel imaging method of Skipped Phase Encoding and Edge Deghosting with Array Coil Enhancement (SPEED-ACE) [3]. This approach is termed (S-SPEED-ACE) and is demonstrated with a phase contrast(PC) MRA study.

Methods

To understand S-SPEED-ACE, it is helpful to review the basics of SPEED-ACE. SPEED-ACE uses multiple coils in parallel and samples k-space with a skip size of N along phase encoding (PE), similar to SENSE [4] and SMASH [5]. The sampled data are first reconstructed by inverse Fourier transform (FT) into a set of sensitivity-weighted, ghosted images, each with N-fold aliasing ghosts as a result of the N-step k-space undersampling. To reduce ghost overlap, a differential filter is used to turn the ghosted images into corresponding ghosted edge maps, which are typically sparse and thus can be adequately described by a double-layer ghost model. This is analogous to the sparsification operation used in compressed sensing [6]. A deghosted edge map is solved and subsequently inverse-filtered into a deghosted image. The central part of k-space (e.g. 32 out of 256 lines) is fully sampled to avoid artifacts in the inverse filtering. One key step in SPEED-ACE is to reduce ghost overlap by using sparseness of image edges [3].

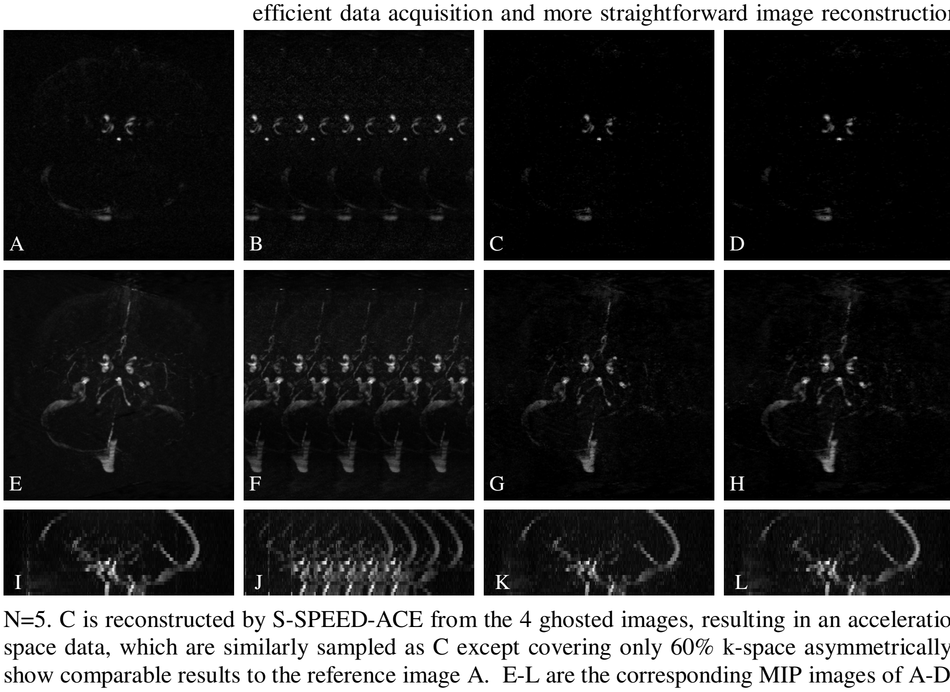
Since data such as MRA are themselves sparse, SPEED-ACE can be simplified by omitting the differential filter for sparsification. The simplified method is named S-SPEED-ACE. Unlike SPEED-ACE, S-SPEED-ACE does not fully sample the central k-space and thus achieves further acceleration. The principle of S-SPEED-ACE can be illustrated by the following example: with a 4-element-coil array, sampling k space at every Nth PE step with a relative shift size of k achieves an acceleration factor of N and yields 4 ghosted images: $I_{1,k}$, $I_{2,k}$, $I_{3,k}$ and $I_{4,k}$, each with N aliasing ghosts. Given the sparsity of the data, $I_{1,k}$ to $I_{4,k}$ are modeled with a single-layer ghost structure. Specifically, the most dominant ghost within the potentially overlapped ghosts at each pixel is selected to represent the signal of that pixel, analogous to the Maximum-Intensity-Projection (MIP) algorithm that selects only the brightest signal even when there are overlapped vessels. In this way, $I_{1,k}$ to $I_{4,k}$ can be described by equations (1-4), where G_n is the dominant ghost; P_k^n is a ghost phasor known to take the form of $[\exp(i2\pi k/N)]^n$, and n = 0,1…N-1 is the order of ghost depending on its relative location; and S_k^n is separately measured coil sensitivity for the ghost of the *nth* order. With a deghosting algorithm based on a least-square-error solution, a single dominant layer of ghost is obtained to yield a deghosted sparse image $I_0(\mathbf{r})$, along with a residual map. The residual map can be used to monitor the quality of the deghosted image. In this way, scan time is reduced by a factor of N. Since S-SPEED-ACE does not use full central k-space sampling and differential filtering as SPEED-ACE does [3], it has more efficient data acquisition and more straightforward image reconstruction. Although the simple single-layer ghost model is often adequate to describe sparse images such as MRA, more layers can be added into the model to improve the solution of S-SPEED-ACE, without cost of additional scan time but with potential noise amplification.

$$I_{1,k} = S_1^n P_k^n G_n \quad (1)$$

$$I_{2,k} = S_2^n P_k^n G_n \quad (2)$$

$$I_{3,k} = S_3^n P_k^n G_n \quad (3)$$

$$I_{4,k} = S_4^n P_k^n G_n \quad (4)$$



S-SPEED was tested with a computer simulated scan, where in vivo PC-MRA data were combined with four coil sensitivity maps from a clinical scanner to generate a 4-coil array PC-MRA data set. The MRA scan was performed on a 1.5 T scanner with a gradient-echo sequence (matrix 256x256, FOV 24 cm, TR 34 ms, TE 6.4 ms, slice thickness 5 mm, flip angle 20°, single acquisition, 25 slices). The MRA images were multiplied by four measured coil sensitivity maps to generate four sensitivity- weighted MRA images.

Results

A is a reference image as one slice obtained from full k-space data. B is one of the 4 ghosted images from the 4 coils with a PE skip size N=5. C is reconstructed by S-SPEED-ACE from the 4 ghosted images, resulting in an acceleration factor of 5. D is reconstructed from only 12% k-space data, which are similarly sampled as C except covering only 60% k-space asymmetrically, achieving an acceleration factor of 8.3. C and D show comparable results to the reference image A. E-L are the corresponding MIP images of A-D from top and side views.

Conclusion

In this work, we presented a parallel imaging method named S-SPEED-ACE for accelerating sparse object imaging. By taking advantage of signal sparsity naturally existing in the data, SPEED-ACE has been simplified and its efficiency has been improved. S-SPEED-ACE is demonstrated with a simulated PC-MRA scan to achieve an acceleration factor of slightly more than 8 using 4 coils.

References

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