Scan Time Reduction with Gradient Energy Minimization (GEM) and Projection onto Convex Sets (POCS)

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Introduction

Scan time is a key consideration in MRI. Many fast imaging strategies such as SENSE [1] have been proposed. This paper presents a new fast imaging method modified from deghosting by Gradient Energy Minimization (GEM) [2,3] and Projection on Convex Sets (POCS) [4,5]. The proposed strategy named by GEM-POCS is simple to implement and reduces scan time considerablely without using additional hardware. The feasibility of the GEM-POCS has been demonstrated with 2D experimental data.

Methods

Theory

In k-space, MR signal is generally peaked at the center and significantly decreases along radial direction, while noise is uniformly distributed [6]. Therefore, central k-space data are acquired with the greatest energy efficiency achieving the best signal-to-noise ratio (SNR). Based on such understanding, the k-space is divided into 2 parts: central part (i.e. low spatial frequencies) and peripheral part (i.e. high spatial frequencies). The central part is fully sampled to yield a low resolution image and to provide an estimate of the phase map which is usually slow varying. The peripheral part is sparsely sampled twice at every Nth phase encoding steps with a shift between the 2 data sets, leading to 2 edge maps with relatively phase rotated aliasing ghosts. These ghosts can be readily suppressed by a previously published GEM algorithm [2,3].

The original GEM was used for motional deghosting, where two ghosted images $I_1 = I_0 + g_1$ and $I_2 = I_0 + g_2$ were treated. A weighted sum of $(I_1 + I_2)/2$ and $(I_1 - I_2)/2$ can be expressed as $I_w = I_0 + (g_1 + g_2)/2 + W(g_1 - g_2)/2$ [3]. A regional weighting coefficient W can be chosen to minimize the ghost terms $(g_1 + g_2)/2 + W(g_1 - g_2)/2$ as measured by "Gradient Energy" [2]. Since in this work the edge maps correspond to the high spatial frequencies or the "gradient" of the image, they can be deghosted by simply performing an energy minimization. This procedure significantly reduces rather than completely eliminates the ghosts from skipped sampling, especially when the ghosts are strong or at small angles between the 2 edge maps. Hence, the deghosted edge map is added to the low resolution image to form an initial guess to be further treated by the POCS algorithm.

$$NDE = \frac{\sum_{FOV} (C_{n+1} - C_n)(C_{n+1} - C_n)^*}{\sum_{FOV} C_n C_n^*} \qquad (1)$$

The POCS process can be divided into 4 steps: (1) The phase of the initial guess is replaced by the phase map estimated from the central k-space data to yield a new image. (2) The new image is Fourier transformed into a new k-space data set. (3) The new k-space data set is partially updated with the original data at those selectively sampled lines, in both the central and peripheral parts. (4) The updated k-space data set is inverse Fourier transformed back into an improved image.

The entire POCS process is repeated until it converges, as measured by the normalized differential energy (NDE) defined in Equation (1), where C represents the complex image, subscripts n and n+1 stand for the number of iterations and $*$ represents complex conjugate. In our practice, the POCS iteration stops if the change of the NDE between sequential iterations is less than 0.01%, typically after a few iterations.

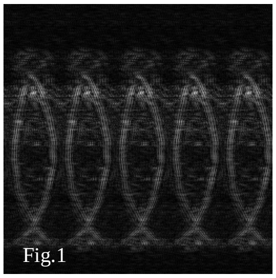
Fig.1

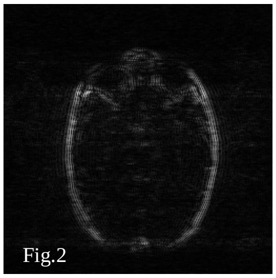
Fig.2

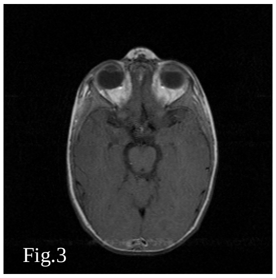
Fig.3

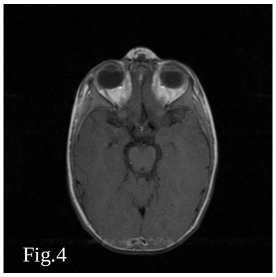
Fig.4

Experiments

The GEM-POCS method was tested with typical 2D experimental MR data from a clinical 1.5 T scanner. Around 60% of a 256x256 k-space matrix was sampled as follows: 90 lines were consecutively sampled near the k-space center. The rest part of k-space is sampled into 2 data sets, with a 5-step-skip (N=5) and a relative shift of 2 lines in the phase encoding direction.

Results

Figure 1 shows one of the 2 magnitude edge maps of a transverse head image, with strong aliasing ghosts in the phase encoding direction due to undersampling. Figure 2 is the magnitude edge map deghosted by the GEM-POCS. In the Figure 2, the aliasing ghosts are significantly suppressed. Figure 3 is the magnitude image of the final result by combining the edge map and the low resolution image obtained from k-space central part. The final result shows no noticeable artifacts and is comparable to the "gold-standard" reconstructed from fully sampled k-space data as shown in Figure 4.

Conclusion

We presented a combined GEM-POCS technique for partial k-space reconstruction and demonstrated its feasibility to speed up image acquisition. The GEM-POCS technique as a general method can be extended to higher dimensions for more potential scan time reduction. The GEM-POCS technique should be useful in MRI applications where the sampling time is a crucial limiting factor.

References

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