Parallel Magnetic Resonance Imaging Reconstruction by Image Editing

J. Shen[1]
[1]NIMH, Bethesda, Maryland, United States

Introduction

In aliased images, pixels from different parts of the field of view overlap. The task of parallel imaging reconstruction is equivalent to extracting each individual pixel from the sum. Magnetic resonance spectroscopy (MRS) has long sought to extract a signal of interest from overlapping signals at the same frequency using various spectral editing techniques. One very effective spectral editing technique uses a two-step procedure (1). In the first step, the intact overlapped spectrum is acquired. In the second step, the signal of interest is selectively inverted via through-bond scalar coupling interactions while leaving the undesired overlapping signals at the same frequency unchanged. An edited spectrum revealing the signal of interest is thus generated by subtracting the perturbed spectrum from the intact spectrum. Here we present a parallel imaging reconstruction method inspired by MRS spectral editing. The original aliased images correspond to the intact spectrum. A perturbed aliased image corresponding to the perturbed spectrum is synthesized using acquired aliased images. In the perturbed images, each pixel is still a complex summation of multiple pixels, but the sign of one pixel in the sum is inverted. The unaliased image for each receive coil can be generated by subtracting the perturbed image from the corresponding intact image using an "image editing" procedure.

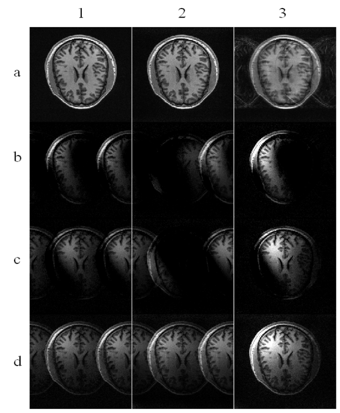

Fig. 1

Theory

Let $A_c(m,n)$ represent the m,n pixel in the aliased image acquired by coil c with an acceleration factor R, where m and n are the pixel index along the readout and phase-encoding directions, respectively. $m \in \{1,M\}$ and $n \in \{1,N/R\}$. We have $A_c(m,n) = \mathrm{sum}_{j=1\sim R}\{U_c(m,n+(j-1)N/R)\}$ [1], where U denotes the unaliased M×N image, and j is the index of aliased FOV. $j \in \{1,R\}$. The perturbed image P for the ith aliased FOV can be expressed as $P_{ic}(m,n) = \mathrm{sum}_{j=1\sim R}\{(-1)^{\delta_{ij}}U_c(m,n+(j-1)N/R)\}$[2], where δ_{ij} is Kronecker's delta. The unaliased images is derived by subtracting the perturbed images from the aliased ones: $U_c(m,n+(j-1)N/R) \propto A_c(m,n)-P_{jc}(m,n)$ [3]. According to Eqs. [1-2], a low-resolution version of $\mathbf{P}_{ic}$ and $\mathbf{A}_c$ images can be calculated from the corresponding low-resolution unaliased image ($\mathbf{u}_c$, $\mathcal{M}\times\mathcal{N}$) using a small, fully sampled k space core ($\mathcal{M}\times\mathcal{N}$). The perturbed low resolution image matrix can be recast into a spatially varying linear combination of aliased images: $\mathbf{p}_c = \mathrm{sum}_{\text{over all coils }(c')}\{s_{c'c}\bullet\mathbf{I}_{1\times R}\otimes\mathbf{a}_{c'}\}$ [4], where $\mathbf{I}_{1\times R} = [1\ldots1]$ is one-dimensional row vector (1×R), C is the total number of receive coils, $s_{c'c}$ is the spatially varying weighting matrix ($\mathcal{M}\times\mathcal{N}$) representing the contribution from coil c' to coil c in the synthesis of $\mathbf{p}_c$, • denotes element-by-element multiplication, and ⊗ denotes tensor product. Eq. [4] can be used to calibrate $s_{c'c}$ after decomposing it into a model functions with spatially invariant coefficients. These coefficients will then be used to synthesize the perturbed high resolution image matrix after interpolating $s_{c'c}$ over M×N. The intended unaliased $\mathbf{U}_c$ can then be calculated or "edited" using Eq. [3].

Methods and Results

Fully sampled MPRAGE images (256x256, slice thickness=1.3 mm acquired at 3T with an eight channel receive coil) were used to test the image editing method. To minimize the difference between $\mathbf{U}_c$ and $\mathbf{A}_c$ images (i.e., to maximally match the image content for better imaging domain fitting) for even-numbered R, the 1~N/2R and N/2R+1~N/R halves of the original aliased images generated by Fourier transform were swapped. Fig. 1 compares the effect of this sub-FOV swapping procedure on the quality of reconstructed images for R = 2. Fig. 1(1a) shows the fully sampled, sum-of-square magnitude MPRAGE image. Fig. 1(2a) shows the edited image. A low-resolution unaliased image (128 × 16) generated from the fully sampled central region of the k space core with eight ACS lines was used to determine the image synthesis kernel according to Eq. [4]. The mean square error is 1.1%. Using direct Fourier transform of the undersampled k space data, the negative frequency half of the aliased image corresponded to sub-FOVs N/4+1~N/2 and 3N/4+1~N; the positive frequency half of the aliased image corresponded to sub-FOVs 1~N/4 and N/2+1~3N/4. If these two halves were not swapped, the resulting and much greater difference between $\mathbf{P}_c$ and $\mathbf{A}_c$ images would put higher demand on the image fitting procedure, leading to poorer reconstructed images. Fig. 1(3a) shows the reconstruction result without applying the swapping procedure to $\mathbf{a}_c$ and $\mathbf{A}_c$ images. To further illustrate the image editing process, Fig 1(1b-3b) shows the positive real mode A_c, P_c images as well as the image subtraction result (U_c) for c = 1 according to Eq. [3]; Fig 1(1c-3c) shows the corresponding positive imaginary mode images; Fig 1(1d-3d) shows the corresponding absolute mode images. For comparison with a standard GRAPPA method developed by Dr. F.H. Lin (http://www.nmr.mgh.harvard.edu/~fhlin/tool_sense.htm, 2) Figs. 2(1a,1b) show the fully sampled MPRAGE image. In Fig. 2(2a), the image editing method (R=3, 22 ACS lines) was employed. The difference image (x8) is shown in Fig. 2(3a). The mean square reconstruction error is 1.4%. The reconstructed image and the difference image(x8) using the standard GRAPPA algorithm was shown in Figs. 2(2b,3b). The GRAPPA reconstruction used 24 ACS lines with a mean square reconstruction error is 1.6%. To investigate potential field-of-view limitations of the proposed image editing method we also performed numerical simulations to examine the effect of prescribing a FOV smaller than the size of the object. The appearance of the aliasing in the reconstructed image was found to be exactly the same as in the unaccelerated image (Fig. 3, R = 3, 1: fully sampled image; 2: image unwrapped using editing; 3: diff.x8).

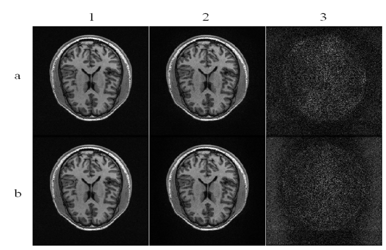

Fig. 2

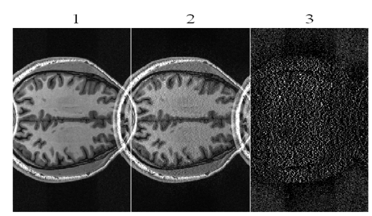

Fig. 3

Discussion

The results showed that image editing is comparable to GRAPPA in terms of reconstruction errors. It is noted, however, image editing used longer computation time than GRAPPA does. This increased computation cost is, in part, due to our data fitting procedure performed in the image domain. The image domain-based SENSE reconstruction method fails when the prescribed FOV in phase-encoding direction is smaller than the region occupied by the object (3). We found that although the image editing method also uses image domain fitting, it does not suffer from this deficiency associated with SENSE. Using image editing, when $s_{c'c}$ is empirically determined using the fully sample k space core no assumption is made on whether the prescribed FOV is larger or smaller than the object. If $\mathbf{A}_c$ contains preexisting aliasing due to the size of unaccelerated FOV being smaller than the size of the object, this preexisting aliasing is passed to $\mathbf{P}_c$ from $\mathbf{A}_c$. In $\mathbf{P}_c$, the sign of pixels originated from subFOVs is reversed sequentially. This sign reversal also applies to any preexisting aliasing in the subFOVs. Other than the two subFOVs located at the two edges along the accelerated direction the sign of the preexisting aliased pixels are not reversed. When $\mathbf{P}_c$ is subtracted out from $\mathbf{A}_c$ to generated reconstructed image $\mathbf{U}_c$, the preexisting aliased pixels are cancelled everywhere in $\mathbf{U}_c$ except at the two edges along the accelerated direction. In conclusion, we demonstrated that parallel imaging reconstruction can be accomplished using image editing, similar to spectral editing in MRS.

References 1. Rothman et al, PNAS, **90**, 5662 (1993). 2. Tsai et al, MRM, **59**, 989 (2008). 3. Griswold et al, MRM. **52**:1118 (2004).