Method for Quality Improvement of Images Reconstructed From Sensitivity Encoded Data

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Reconstruction from sensitivity-encoded data at high reduction factors usually generates images of poor quality. We have developed the method for refinement of the images reconstructed from sensitivity-encoded data. The method uses phase smoothness assumption and iterations of alternating Projections Onto Convex Sets (POCS). The phase of initially reconstructed image is smoothed and then used as constraining convex set. Other convex sets are formed by the available k-space data and coil sensitivity profiles. The final image corresponds to the intersection of the convex sets. The method efficiency was demonstrated with phantom images reconstructed by SENSE (SENSitivity Encoding) method.

Introduction

Several techniques such as SENSE [1] and SMASH [2] (SiMultaneous Acquisition of Spatial Harmonics) have been recently proposed for reconstruction of sensitivity encoded data. The degradation of SENSE/SMASH reconstructed images by noise component at high reduction factors often presents a serious problem in image analysis. One way to improve the quality of reconstruction is to use a prior knowledge. In MRI, the phase often exhibits smoothness property that is used, for example, in reconstruction of partial Fourier data [3,4]. Using this property directly in SENSE/SMASH reconstruction may not be possible or may lead to the non-linearity of problem formulation.

In the paper, we present a novel method that efficiently denoises SENSE/SMASH images. The method uses the only assumption that phase is smoothly varying across the tissues areas of the image.

Method

Recently, POCSENSE (POCS-based method for reconstruction from SENSitivity Encoded data) has been proposed [5]. It finds the resulting image as the intersection of the convex sets defined by the following projection operators: P_1^i is a projection onto the set of images acquired by the coil with given sensitivity, P_2 is a projection onto the set of images with k-space equivalent to the acquired k-space data, P_3 is a projection on the set of images with given support in image space. We define the additional convex set to be the set of images with a given image phase $\tilde{\phi}_{true}$ and corresponding projection operator P_ϕ:

$$P_\phi g^{(n)} = \left|g^{(n)}\right| \cdot e^{i\tilde{\phi}_{true}}$$

where $g^{(n)} = g^{(n)}(r)$ is an image approximation on n_{th}-step. We construct $\tilde{\phi}_{true}$ by smoothing the phase of initially reconstructed image $g^{(0)}(r)$. The algorithm starts with initial quess $g^{(0)} = g^{(0)}(r)$ and proceed until convergence as follows:

$$g_i^{(n)} = P_3 P_2 P_1^i P_\phi g^{(n-1)}, \quad i = 1 \ldots N,$$

$$g^{(n)} = \left(\sum_{i=1}^{N} w_i g_i^{(n)} S_i^*\right) \Big/ \left(\sum_{j=1}^{N} w_j S_j S_j^*\right).$$

where N is the number of coils, S_i and S_i^* - complex sensitivity of i-th coil and its complex conjugate, $w_i = 1/\sigma_i^2$, σ_i - noise standard deviation in i-th channel, $g_i^{(n)} = g_i^{(n)}(r)$ - reconstructed image acquired by i-th coil after n iteration [5].

Results

Reference and folded images of a phantom were acquired on a 1.5 GE SIGNA (GE Medical Systems, Milwaukee, WI) using 4-coil phased array and GRE sequence. SENSE method [1] was used for reconstruction from the sensitivity - encoded data with reduction factor R=4. For demonstration purposes, we used local polynomial fit for image phase smoothing as described in [1]. No smoothing was attempted near object boundaries. The smoothed phase was used in defining the proposed convex set. Figure 1 shows the map of noise standard deviations as predicted by SENSE analysis [1] for the reconstructed image, the phase of the image, and the smoothed phase, $\tilde{\phi}_{true}$. It demonstrates the existence of correlation between noise level and local phase fluctuations. The SENSE image was used as initial guess in the proposed method. Figure 2 shows that the resulting image has considerable higher quality than the initial SENSE image. The improvement of image quality is especially obvious in area with high noise level.

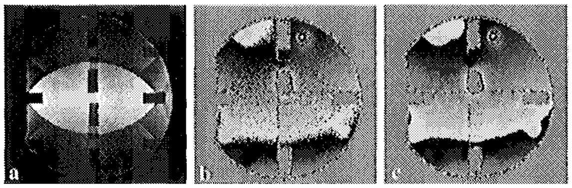

Figure 1. (**a**) Noise map of SENSE reconstructed image; (**b**) phase of initial image (after SENSE reconstruction); (**c**) smoothed phase, $\tilde{\phi}_{true}$

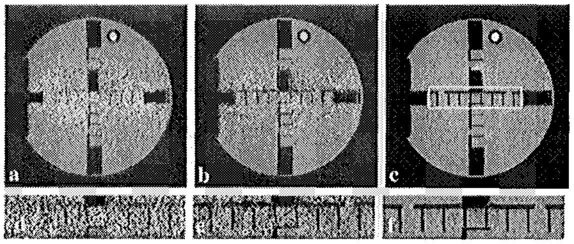

Figure 2. (**a**) Initial image (after SENSE reconstruction); (**b**) the resulting image (after 15 POCSENSE iterations); (**c**) the image reconstructed using complete data. White rectangular marks the region of interest (ROI); (**d-f**) Zoomed ROI of (a-c).

Discussion

We developed a novel technique for quality improvement of images reconstructed from sensitivity encoded data. The method uses phase smoothness assumption to obtain estimation of underlying image phase by non-linear smoothing that is then used as additional convex set in POCSENSE iterations. The assumption holds well for spin echo images, while gradient echo images may require adaptive smoothing approach that would apply less smoothing near object edges where the assumption often fails. The results of simulations and phantom studies show promising results for the post-reconstruction quality improvement of SENSE/SMASH images. The method is especially useful for high and maximum reduction factors and for non-optimized coil geometries when there could be significant degradation of the image by the noise component. Further studies are required for development of optimal and fast filtering algorithm for phase smoothing.

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