JOINT ESTIMATION BASED PHASE ERROR CORRECTION IN MULTI-SHOT SPIRAL DIFFUSION WEIGHTED IMAGING

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TARGET AUDIENCE: Researchers and clinicians interested in high resolution DWI

PURPOSE: Multi-shot spiral imaging is a typical method used to achieve high resolution in diffusion-weighted imaging (DWI). However, it has been shown that involuntary motion of the subject will lead to phase errors in image space [5], and the phase inconsistencies between different shots will introduce artifacts in the final reconstructed image. Traditionally, with variable-density spiral (VDS) technique or navigator data, such artifacts can be removed [4]. Iteratively Regularized Gauss-Newton method (IRGN) [1] has been used as a method of joint estimation of sensitivity map and objects function, and also has been mentioned as an alternative to conventional reconstruction methods in DWI using EPI trajectory [2]. Here, we extended IRGN algorithm in multi-shot spiral imaging of DWI to jointly estimate motion induced phase errors and the object function. Preliminary results show that by using little amount of oversampling in the k-space center, our proposed method provide more accurate estimation of the object function than that derived from VDS technique.

THEORY: MRI signals in k-space obtained from N shots is given by

$$K_j = F_j(Ie^{i\phi_j}) \qquad j = 1,...N.$$

where the index describes the shot j of a multishot acquisition; I denotes the motion free image to be reconstructed; ϕ_j is the motion-induced phase error for shot j; F_j is an operator which maps the object function and the phase map of shot j to the measured k-space data K_j. This nonlinear equation can be solved by IRGN method using the proposed new model which estimates the image I and phase map ϕ_j at the same time.

$$I, \{\phi_j\} = \arg\min \sum_{j=1}^{Nch} \left\| F(I \cdot e^{i\phi_j}) - K_j \right\|_2^2 + \alpha \left\| I - I_0 \right\|_2^2 \qquad j = 1,...N$$

In this work, we only consider the linear component of the motion-induced phase error. Thus the regularization of IRGN by penalizing high frequencies to enforce the smoothness of the phase map can be directly applied here.

METHODS: To validate the proposed concept, only numerical simulations were performed due to limited imaging sequence access. Firstly, an unaliased diffusion weighted image is acquired by using the iterative phase correction [3], which was used as a reference image. Secondly, k-space data was sampled by 2 interleaved spiral trajectories, each consisting of a variable density spiral using a modified version of Hargreaves' code [6]. Thirdly, random linear phase error was added to both of the two shots. Lastly, the motion-free image and phase map were estimated using the proposed method.

The reference DW image was obtained on a GE 3T HD MRI scanner (GE Healthcare, Milwaukee, WI) with an eight-channel RF coil and a gradient system. A spin-echo spiral imaging pulse sequence was used with the following parameters: repetition time = 5s, echo time = 56ms, FOV = 24cm, matrix size = 96*96, slice thickness = 2.5mm.

RESULTS AND DISCUSSION: Representative results are shown in Fig. 1. In this case, there is a global phase difference of π between 2 shots, which we consider as the most severe situation. Compared to the reference image (Fig. 1a1), the image (Fig. 1a2) after adding a linear phase error suffers from aliasing artifacts as well as signal loss. The image (Fig. 1b2) obtained by the proposed method provides a much improved estimation of the object function, while the image (Fig. 1b1) derived from the direct phase correction using the self-navigator data has unsuppressed noise in the background and still has some residual artifacts as pointed by the arrows.
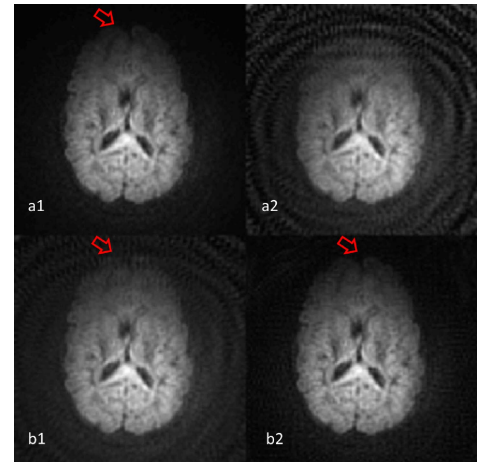

Fig. 1 Simulation results. a1) reference image; a2) without motion correction; b1) self-navigator correction; b2) result from the proposed method.

It is noteworthy that even in case of using regular spiral trajectory, which means the center of the k-space is not oversampled, our method still to some extend works and removes most of the motion-induced artifacts, but leads to image with increasing noise. Therefore, minor oversampling in the k-space can improve the performance of this method. The long readout window required by the traditional VDS DWI might be alleviated.

CONCLUSION: A new method which jointly estimates object function and motion-induced phase errors in muti-shot spiral DWI is proposed, and is validated by the simulation results. Our proof-of-concept work demonstrates that this method can estimate the desired artifact-free image more accurately than self-navigator based technique when navigator information is limited. Thus, it has potential utilization in high resolution diffusion weighted imaging with multi-shot technique when the readout window is critical. Further work will be performed to apply this method to reconstruct images from *in vivo* data with real motion-induced phase errors.

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