# Field–Corrected Imaging Using Joint Estimation of Image and Field Map

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## 1 Abstract

In order to reduce acquisition time in dynamic scans, while still correcting for field inhomogeneities, an image reconstruction method is introduced that simultaneously estimates field-corrected images and their associated field maps while acquiring only part of k-space at each readout. A two-shot variable density spiral sequence is combined with a regularized nonlinear least-squares joint field map and image estimation method to yield a field-corrected image between every pair of readouts, while acquiring only a little over half the k-space data at each readout.

## 2 Introduction

Field inhomogeneities such as those present near air/tissue boundaries in the brain cause image distortions when imaging with non-cartesian k-space trajectories. Many methods have been proposed to correct the images when the field map is known, including conjugate phase [4, 5], SPHERE [2] and iterative methods [1]. The standard method to estimate field maps is to acquire full FOV images at two different echo times and divide the pixel-by-pixel phase difference by the difference in echo times. In order to reduce acquisition time in dynamic scans, we proposed a reduced k-space sampling scheme where only part of k-space is acquired at adjacent time points with different echo times. Then the image and field map are jointly estimated by minimizing a cost function based on modeling the data using the signal equation.

## 3 Methods

We used a two-shot variable density spiral (VD) trajectory in an alternating echo-time sequence (24cm FOV, 64 mtx size, 25ms TE, for 1936 k-space points for each interleave verses 3568 for a single shot). Each shot of the VD spiral supported a 10 by 10 full FOV image. We acquired alternating shots of the two-shot spiral at the alternating echo times, ie. we acquired shot 1 at echo time 1 followed by shot 2 at echo time 2, then back to shot 1 at echo time 1. The VD spiral is used so that a low resolution, full FOV field map can be determined using just the central portion of k-space from adjacent time points. A similar approach to get a low resolution field map for projection reconstruction was used in [3]. This low resolution field map, estimated in the standard way, is used as an initial guess in our iterative algorithm. The cost function we minimize is:

$$J(\boldsymbol{m},\omega_0) = \frac{1}{2}\sum_i |(y_i - u_i(\boldsymbol{m},\omega_0))|^2 + |(z_i - v_i(\boldsymbol{m},\omega_0))|^2 + \beta \sum_{j_1,j_2 \text{ neighbors}} (\omega_0(r_{j_1}) - \omega_0(r_{j_2}))^2, \quad (1)$$

where $\boldsymbol{y}$ and $\boldsymbol{z}$ are the data at the two echo times, $\boldsymbol{u}$ and $\boldsymbol{v}$ are the modeled signal equation, depending on the estimated image, $\boldsymbol{m}$, and field map, $\omega_0$. The last term penalizes differences between the field map at adjacent pixels to ensure a smooth field map. Since the cost function depends on the current estimate of both the field map and the image, we alternate reconstructing the image using our current estimate of the field map and then updating the field map using the current estimate of the image. We take advantage of the linearity of the image reconstruction problem and use the conjugate gradient method to find an estimate of the image using all of the data from both time points. Taking the derivative of the cost function with respect to $\omega_0(r_j)$, we can update the estimate of the field map using gradient descent.

## 4 Results

First, a simulation object based on an imaged brain slice and its corresponding measured field map was used to synthesize k-space to verify our method. A comparison of the error in the uncorrected image, the corrected image using the low resolution field map, and our simultaneously estimated image is shown in Figure 1.

Then, a scan with the previous trajectory parameters was implemented on a GE 3T Signa Scanner (GE Medical Systems, Milwaukee, WI). A corrected image from a single shot dynamic study is shown in Figure 2 along with the simultaneously estimated image and field map from a two-shot VD spiral study using the pulse sequence described previously. Note that the two-shot VD spiral study uses only a little more than half of the data of the single shot study.

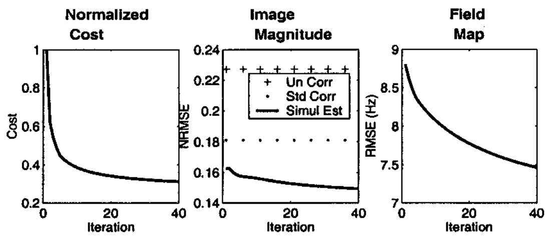


Figure 1: Results from simulation. Cost function was normalized to error at end of first iteration. Image magnitude error plot shows results from applying no correction, a standard correction, and the results from the simultaneous estimation. The error of the simultaneously estimated field map is also given over iteration.

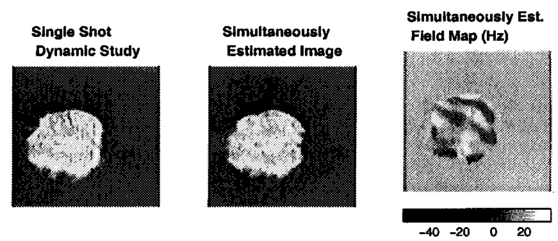


Figure 2: A comparison of image from a single shot dynamic study (standard correction) with that from a two-shot VD spiral trajectory with the proposed reconstruction scheme along with its simultaneously estimated field map.

## 5 Discussion

Our regularized nonlinear least-squares joint field map and image estimation method has allowed for the efficient use of interleaved data to reconstruct field-corrected images while acquiring only a few more k-space points than one interleave of a two shot sequence at each time point. When a running field map is desired, this acquisition scheme may allow for an increase in the number of slices in a dynamic study.

## References

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