Linear Correction of Inhomogeneity for Fast 3D Spiral Imaging

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Introduction: Fast scanning methods with time varying gradients have extensively been studied and developed both for 2D and 3D MR imaging. One of the problems that restricts the usage of these methods is off-resonance effects, which appear as blur in the reconstructed image. Off resonance is even a more difficult problem in 3D imaging because of the bigger volume involved. There are well known methods for off-resonance compensation based on a preacquired field map, such as conjugate phase reconstruction [1,2]. Unfortunately, most of these methods are computationally intensive, which specifically makes them impractical for 3D data sets. This work introduces the 3D extension of a fast and robust algorithm based on linear estimation of field map [3].

Methods: We can write the MR signal as

\[ S(t) = \int m(r)e^{-j2\pi f(r)t}e^{-j2\pi k_r(t)\cdot r}dr \]  

(1)

where \( r = [x, y, z] \) is the 3D position vector, \( k_r(t) \) is the time integral of the gradient fields, and \( f(r) \) is the field map; i.e. the local frequency deviation. Ideally, off-resonance is zero and \( S(t) \) is simply the Fourier transform of the image evaluated at spatial frequency \( k_r = k_r(t) \). In this case, the image can be recovered from scanned data just by gridding and FFT. Unfortunately, this fast reconstruction algorithm cannot be employed in most practical cases where \( f(r) \) is not zero. Nevertheless, we can substantially reduce the computational complexity by assuming a linear structure for field map. Namely, we approximate \( f(r) \) as

\[ f(r) \approx \hat{f}(r) = f_0 + \alpha \cdot r \]  

(2)

where \( \alpha = [\alpha_x, \alpha_y, \alpha_z] \) is a constant vector. With this approximation, Eq. 1 is

interested in the general linear structure of the map and not in its local details. This fact substantially reduces both the scan time and the reconstruction time for field map.

Linear map: We need to approximate the off-resonance with a linear map as in Eq. 2. The parameters of the linear map, \( f_0 \) and \( \alpha \), are chosen to minimize the weighted mean square error of this approximation. The weighting factor is set to the intensity of the image, for two reasons. First we are not interested in the values of off-resonance outside the object. Second the fieldmap is less accurate in places with low intensity.

Results: We used a Stack of Spiral trajectory [5] to acquire 3D images. The FOV is 24 x 24 x 3 cm and the voxel size is less than 2 x 2 x 2 mm. The TR/TE are 60/8 msec. The field map has been computed from two scans with 1 msec difference in echo time. The number of excitation for the original image and the field map are 148 and 28, respectively. FOV of the field map is the same as the original image but its voxel size is 8 times larger. The sequence has been implemented on a GE 1.5T SIGNA. Fig. 1 shows the application of linear off-resonance correction to 3D phase contrast angiography of the head. Vessel sharpness is significantly improved in corrected image. Total scan time for this sequence is less than one minute.