OFF-RESONANCE CORRECTION FOR 3D CONES IMAGING USING MULTIFREQUENCY INTERPOLATION

Wendy W Ni[1,2], Holden H Wu[1,3], and Dwight G Nishimura[1]

[1]*Department of Electrical Engineering, Stanford University, Stanford, California, United States,* [2]*Department of Radiology, Stanford University, Stanford, California, United States,* [3]*Department of Cardiovascular Medicine, Stanford University, Stanford, California, United States*

Introduction: 3D non-Cartesian trajectories, such as the 3D cones [1], provide unique advantages for applications including MR angiography, cardiac imaging, short-T2 imaging and sodium imaging. However, off-resonance effects may manifest as image blurring if not appropriately addressed [2]. Multifrequency interpolation (MFI) is a frequency-segmented technique developed for fast and computationally efficient off-resonance correction in 2D non-Cartesian imaging [3]. In this study, we extend the MFI algorithm to 3D off-resonance correction and demonstrate its feasibility for correcting data acquired using the 3D cones trajectory.

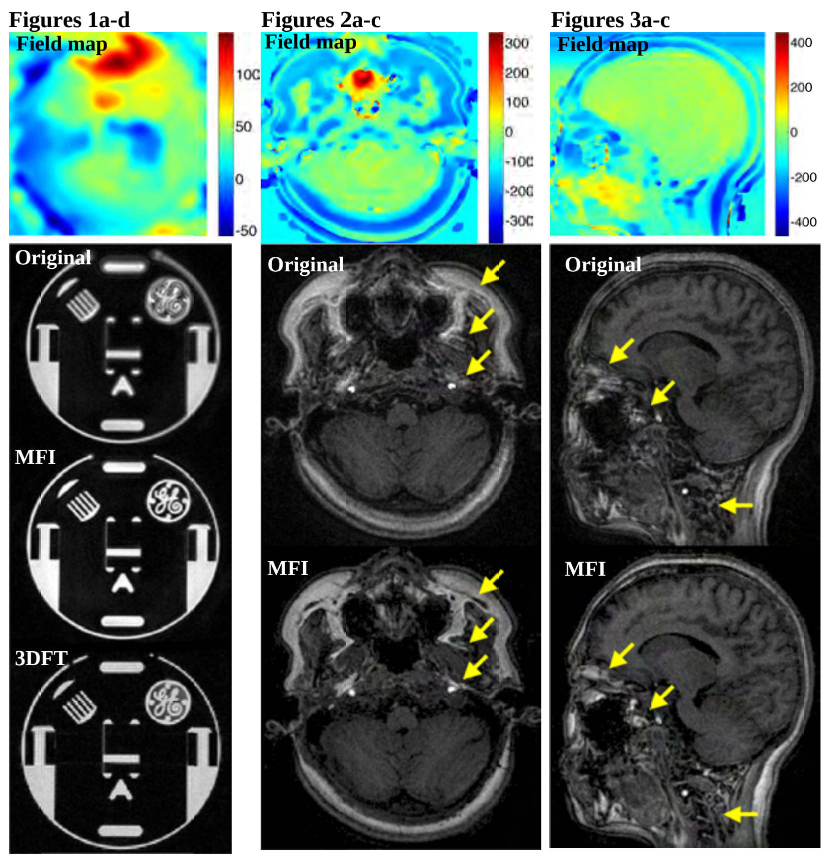
Methods: We implemented a 3D cones gradient-echo (GRE) sequence and obtained data on a 1.5T GE Signa Excite scanner. For phantom scans, we used a 30° flip angle, isotropic 20 cm FOV at isotropic 1 mm resolution, TR of 14.8 ms and 3438 excitations with readout duration (T) of 9.3 ms. *In vivo* head data from a volunteer was also acquired with 30° flip angle, additional RF spoiling, isotropic 25.6 cm FOV at isotropic 1 mm resolution, TR of 30 ms, 6878 excitations with T of 7.3 ms, and scan time of 3 min 28 s.

For these feasibility studies, we acquired two full-resolution data sets at TE = 0.652 ms and 1.652 ms, so that we could retrospectively emulate 3D field maps [4] with different spatial resolutions. Low-resolution 3D field maps were generated by windowing the two sets of k-space data to retain a sphere in the center of k-space. The maps were then masked to remove low-SNR areas and denoised with a 3^3 median filter. Subsequently, the range of off-resonance frequencies was divided into L equal segments to provide L+1 demodulation frequencies used to create base images. In our implementation, L is the smallest even number exceeding the minimum value L_{min} derived in [3]. Using an even L ensured that one base image has demodulation frequency of 0. Voxel-wise off-resonance correction was performed via a linear combination of the L+1 complex base images. 101 sets of L+1 coefficients were pre-computed to allow synthesis at any desired demodulation frequency within the range of the field map. For the phantom experiment, 3DFT images with the same FOV and resolution were also acquired for comparison.

Results and Discussion: In practice, the field map could be acquired in a rapid calibration scan. Clearly, the performance of MFI depends greatly on the field map. For the results shown below, we emulated a low-resolution 3D field map with k-space extent $k_r=0.2k_{r,max}$ (where $k_{r,max}$ is the k-space extent at full resolution), equivalent to a spatial resolution of 5 mm. At an isotropic 25.6-cm FOV (as used for the head scan), such a field map could be acquired using 468 cone readouts with T = 2.66 ms and TR = 6 ms in a total scan time of 2.8 s per TE setting. Higher resolution field maps are preferable, but of course entail longer additional scan times. Reasonable performance was achieved using a voxel dimension five times larger than the image resolution.

Using the field map described above, we observed off-resonance frequency ranges of -157 to 244Hz for the phantom and -477 to 483Hz for the head. Hence L=6 (phantom) and 10 (head). After MFI correction was applied, both phantom and *in vivo* results showed significant reduction in blurring. Better contrast was achieved and previously unrecognizable anatomic structures emerged especially in regions affected by local field variations due to susceptibility discontinuities such as air-tissue interfaces, and water-fat interfaces (regions with high absolute off-resonance in Figures 1a and 2a).

We have demonstrated the feasibility of 3D MFI off-resonance correction to refocus image blurring and improve image quality for 3D cones imaging. This allows us to use long readout durations and achieve high SNR efficiency for the 3D cones [1]. In addition, the 3D cones trajectory requires significantly fewer excitations. In comparison to 3DFT, at the same FOV and resolution for our data sets, 3D cones require only 8.6% of the number of excitations for the phantom, and 10.5% for the head. Our MFI technique can also be combined with gradient non-linearity correction and concomitant field correction [5] to further improve image quality.



Figures 1a-d: The MFI-corrected phantom image is in focus everywhere and comparable to the 3DFT image.
Figures 2a-c: Significant improvement is made by MFI around the nasal cavity and in the face region, especially the subcutaneous fat, cartilage and blood vessels. The fat around the skull has also sharpened after correction.
Figures 3a-c: Regions of significant improvement include the areas superior and posterior to the nasal cavity, and near the spine.

References: [1] Gurney *et al.*, MRM, 2006. [2] M O'Donnell and W Edelstein, Med. Phys., 1985. [3] L-C Man *et al.*, MRM, 1997. [4] P Irarrazabal *et al.*, MRM 1996. [5] J Cheng *et al.*, MRM 2011.