

# Fast Field Inhomogeneity and Concomitant Gradient Field Correction in Spiral Cardiac Imaging

J. Y. Cheng<sup>1</sup>, J. M. Santos<sup>1,2</sup>, and J. M. Pauly<sup>1</sup>

<sup>1</sup>Electrical Engineering, Stanford University, Stanford, CA, United States, <sup>2</sup>HeartVista, Inc., Los Altos, CA, United States

**Introduction:** Cardiac imaging, for both real-time and triggered imaging, requires a high data acquisition rate. Spiral trajectories achieve this rate; however, their advantages are shadowed by off-resonance blurring and distortion effects. Current techniques to correct for this image degradation do not easily or quickly account for the different effects - specifically field inhomogeneities and concomitant gradient fields [1-3]. We present two fast and accurate algorithms to correct for both of these effects. Speed is demonstrated in a real-time study, and accuracy is shown in a high-resolution study.

**Methods:** Off-resonance effects can be modeled as a non-stationary convolution applied to an image  $I(\mathbf{x})$ , resulting in the following function:  $I_c(\mathbf{x}) = \int I(\mathbf{x}') f(\mathbf{x}', \mathbf{x} - \mathbf{x}') d\mathbf{x}'$ . The correction problem involved finding a deconvolution solution. Because the spiral trajectory has a smooth point spread function, the kernel  $f(\mathbf{x}', \mathbf{x})$  can be fit to a quadratic phase model using the measured field inhomogeneities and the calculated concomitant gradient fields.

In search for a fast and accurate algorithm, we perform the deconvolution post-gridding through two methods: (1) multi-frequency interpolation (MFI) [2,4] with 10 frequency bins, and (2) image space non-stationary convolution [2,5] with a set of 1000 precomputed kernels of 20 pixel width. A field map was acquired using a low-resolution (6.5 mm) single-shot spiral at  $TE_1/TE_2 = 3.84/8.45$  ms. The algorithms were implemented on a real-time MR system, RTHawk [6], for an 1.5 T GE Signa EXCITE scanner.

A phantom study was used to analyze the off-resonance effects and the methods used. A real-time study and a triggered high-resolution cardiac study were conducted to test the effectiveness of our approach. A 4 interleave spiral with  $FOV = 200$  mm,  $TE/TR = 3.84/22.32$  ms, slice thickness = 5 mm, and resolution = 1.89 mm was used for the real-time study. For the high-resolution (0.72 mm) study, the spiral had 16 interleaves with the same  $TE/TR$  and slice thickness. Data acquired with an 8-channel cardiac coil were corrected separately before combined using sum-of-squares.

**Results and Discussion:** The MFI method and the image convolution method yielded nearly indistinguishable results (Fig. 1), so we only present the image convolution method for the cardiac studies. Also, the computation time for the two methods were quite similar, so either algorithm is recommended. One caveat: for highly varying off-resonance maps, the MFI method manifested small discretization artifacts. Also seen in Fig. 1, correcting for only the field inhomogeneity or only the concomitant gradient fields was insufficient; both need to be accounted for. The off-resonance maps gives a good indication of where each effects blurred the scan and to what degree.

To test the speed, the algorithms were used in a real-time cardiac study (Fig. 2). Using our unoptimized code on a platform with 2.13 GHz Intel Dual Core and 4 GB of RAM, we measured a correction rate of  $\sim 0.1$  s/slice. This kept up with our frame rate of 11.2 fps. The computation time manifested itself as a 0.1 s latency. If the frame rate is faster than the correction rate (e.g. using a sliding window reconstruction), data have to be discarded. To demonstrate accuracy, the methods were used to correct high-resolution cardiac images (Fig. 3). An increase in sharpness in the atrial wall and coronary artery is apparent. The remaining artifacts can be partially attributed to chemical shifts and motion blurring.

**Conclusion:** We propose effective and fast algorithms to correct for both the main field inhomogeneity and concomitant gradient field that are suitable for cardiac studies.

**References:** [1] King *et al*, MRM 41, 1999. [2] Cheng *et al*, ISMRM 2844, 2009. [3] Chen *et al*, MRM 60, 2008. [4] Man *et al*, MRM 37, 1997. [5] Ahunbay & Pipe, MRM 44, 2000. [6] Santos *et al*, IEEE EMBS 2, 2004.

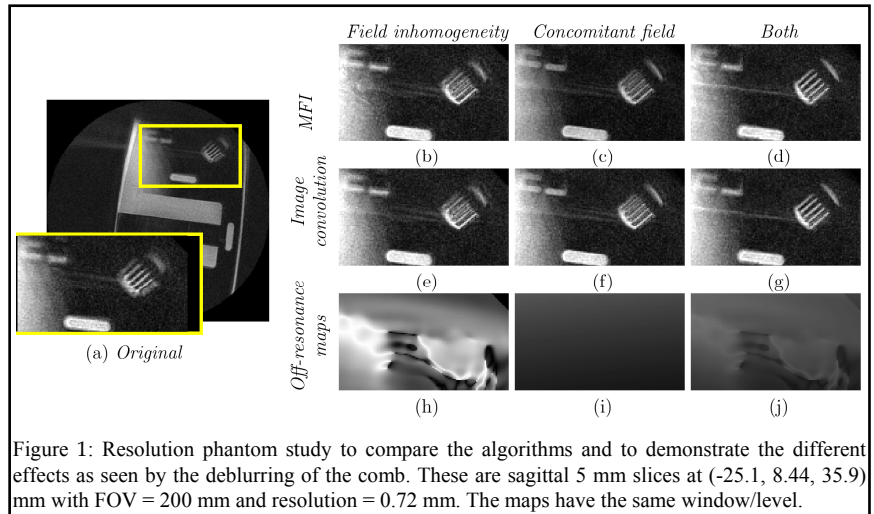


Figure 1: Resolution phantom study to compare the algorithms and to demonstrate the different effects as seen by the deblurring of the comb. These are sagittal 5 mm slices at (-25.1, 8.44, 35.9) mm with  $FOV = 200$  mm and resolution = 0.72 mm. The maps have the same window/level.

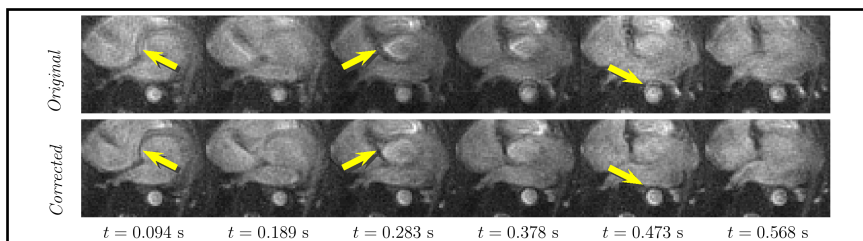


Figure 2: Sequential axial slices from a real-time cardiac study corrected using the image convolution method. The deblurring is noticeable in the aorta and atrial walls with some residue blurring partially due to motion blurring. The 5 mm slices were obtained at (17.19,-0.78,-50.0) mm.

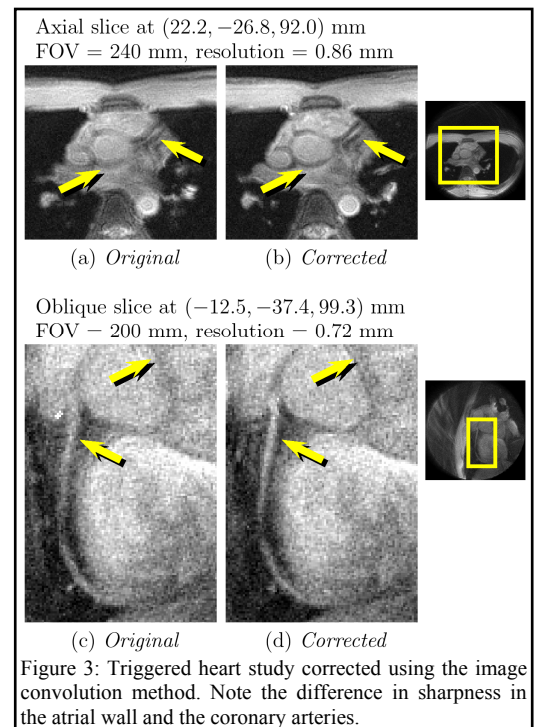


Figure 3: Triggered heart study corrected using the image convolution method. Note the difference in sharpness in the atrial wall and the coronary arteries.