An automatic off-resonance correction method for multi-slice imaging

W. Chen[1], C. H. Meyer[1]

[1]Biomedical Engineering, University of Virginia, Charlottesville, VA, United States

Introduction: Non 2DFT k-space trajectories increase scan efficiency but can lead to image blurring in the presence of field inhomogeneity. Many field map based off-resonance correction methods have been presented in the literature. The extra field map acquisition, however, prolongs the scan time. Field-map based methods sometimes can also become unreliable when the field map itself is seriously blurred or distorted by strong field inhomogeneity. Automatic off-resonance correction methods [1, 2] can partly solve these problems, because these methods estimate a field map directly from the image data. However, automatic methods are prone to estimation error, especially at structure interfaces or regions with low signal. When applying automatic methods to multi-slice imaging, the field map can have large discontinuities in the slice direction due to estimation error. In this abstract, we propose an automatic off-resonance correction method for multi-slice imaging with improved robustness compared to regular automatic methods. We use the continuity of the underlying field to impose constraints on the calculation of the field maps for neighboring slices. We demonstrate our algorithm on a multi-slice breath-held spiral coronary imaging dataset.

Methods: For auto-focusing methods, a set of complex images are reconstructed from signals demodulated at various frequencies within an off-resonance frequency range. The field map is then determined pixel by pixel by minimizing a pre-defined objective function which is calculated over all these images. An effective objective function proposed by Noll *et al* [1] is the summation within a local window of the absolute value of the imaginary image raised to a certain power. When applying auto-focusing methods to a single slice image, due to the lack of *a priori* knowledge of the off-resonance, we usually need to search over a large frequency range to determine a field map, which can lead to a spurious minimum of the objective function. To avoid a spurious minimum, a large summation window is usually used, but this can result in an over-smoothed field map. Man *et al* [2] proposed a two-stage automatic method to reduce this problem: in the first stage, they estimate a field map with low frequency resolution, and then in the second stage, they determine a field map with high frequency resolution by searching within a narrow spatially-varying frequency range. Searching within a narrow frequency range allows a small summation window to be used, which avoids over smoothing the field map. The same idea can be used to reduce the estimation error when applying automatic off-resonance correction to multi-slice imaging. Since the underlying field is continuous along the slice direction, we can use the field map determined for one slice to reduce the range of frequencies that we have to search in neighboring slices. The following is the algorithm we propose to perform multi-slice automatic deblurring: a) Use an automatic method to determine a field map for an initial slice. The field map is smoothed and then used as a frequency constraint for the neighboring slice; b) For the neighboring slice, at each pixel (x,y), we search in a spatially-varying frequency range, $\left[f_1(x,y)-\Delta f, f_1(x,y)+\Delta f\right]$, to determine the field value at that pixel, where Δf is a predefined constant frequency offset reflecting the level of smoothness along the slice direction, and $f_1(x,y)$ is the field map from the previous slice at the pixel location (x,y). When calculating the objective function, we use the multiple frequency interpolation method [3] to calculate the image value at various frequencies within the summation window. The interpolation coefficients for the multiple frequency interpolation method can be pre-calculated and saved off-line, and loaded later during image reconstruction. After obtaining the full field map, it is smoothed and then we proceed to the next slice. In our algorithm, since the estimation error can be propagated to the following slices, the field map estimated from the initial slice is important. To reduce the estimation error, we can acquire an extra low-resolution field map for the initial slice and use it to calibrate the field map estimated by automatic method. In general, we choose the center slice or the slice with best signal as the initial slice to reduce the possible estimation error.

Results: We applied our algorithm on multiple datasets. All the results indicated our algorithm is more robust than automatic deblurring without a field constraint in the slice direction. Figure 1 shows the results on one of the datasets we tested. The multi-slice data were acquired with a gated, breath-held, gradient echo spiral scan of the coronary vessels of a normal volunteer on a Siemens Sonata 1.5 T scanner (Siemens Medical Solutions). A presaturation pulse was used to suppress fat. The readout for each slice was done with 14 interleaved spirals each of 16.38 ms readout duration. A low resolution field map was collected for the first slice. The frequency offset Δf was chosen as 20 Hz. For comparison, we also performed Noll *et al*'s automatic method without a field constraint in the slice direction. The first row in Fig. 1 shows that the two methods achieved similar deblurring in the first slice. The second row in Fig. 1 shows that Noll *et al*'s method became unstable at the boundaries of coronary vessels, whereas after applying the field constraint in the slice direction, the automatic method achieves good deblurring at these locations.

Discussion and Conclusion: We proposed an automatic off-resonance correction algorithm for multi-slice imaging. We apply a field constraint in the slice direction to reduce the chance of estimation error of automatic methods in low signal regions or at structure interfaces. This technique may be useful in multi-slice spiral coronary imaging where the low signal regions at the interface between the coronary arteries and air can cause estimation error in regular automatic methods.

Reference: [1] Noll et al MRM 25: 319-333 (1992) [2] Man et al. MRM 37: 906-913 (1997) [3] Man et al. MRM 37: 906-913 (1997)

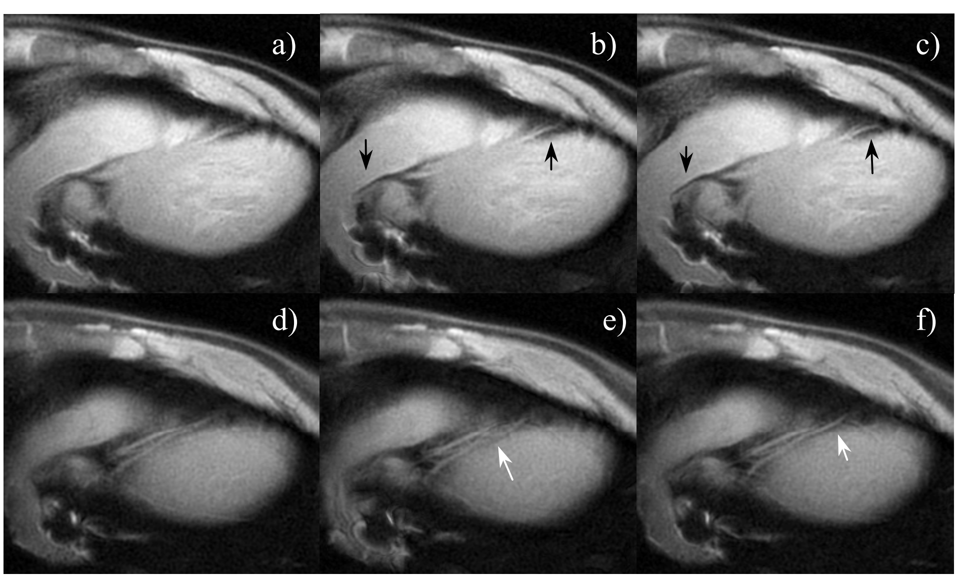

Figure 1: A multi-slice coronary vessel scan with no deblurring, a) and d), with Noll *et al*'s automatic off-resonance correction, b) and e), and with our deblurring algorithm, c) and f). The first row, a), b) and c), corresponds to the first slice. The second row, d), e) and f), corresponds to the second slice. Note that Noll's method achieved similar deblurring as our method in the first slice (the deblurred area is indicated by black arrow). However, Noll's method lost robustness at the boundaries of the coronary vessels (indicated by white arrow) in the second slice, whereas our method achieved better defined coronary vessels (indicated by white arrow) compared to the image with no deblurring.