Fast automatic debluring with a linear map

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Introduction: For non-2DFT data acquisition, image blurring occurs when there is field inhomogeneity. Most deblurring methods require the acquisition of an extra dataset to estimate a field map. The field map based deblurring methods, however, prolong the scan time. This makes them undesirable for real time imaging and dynamic imaging, where the inhomogeneity can vary during the time course due to the cardiac and respiratory effects. Extra field map acquisitions are also undesirable in hyperpolarized gas imaging, since the signal can decay quickly after excitation due to the inequilibrium of the hyperpolarized gas. The acquired field map sometimes can be unreliable when there is strong inhomogeneity because the map itself can be blurred and distorted. Automatic methods [1,2] are an alternative in these conditions. They can estimate a field map directly from the blurred image itself. However, automatic methods are computationally inefficient and can lose robustness in regions with low signal-noise ratio. In this abstract, we propose a fast automatic linear off-resonance correction method. Our method needs only about two times the computation time of gridding, and it is more robust than pixel-by-pixel based automatic methods in regions with low SNR.

Method: For auto-focusing methods, the data is demodulated at a set of equally separated frequencies. The field map is then calculated pixel by pixel by minimizing a pre-defined objective function [1]. The linear automatic off-resonance correction algorithm we propose is to estimate a field map by using Noll *et al*'s pixel-by-pixel based automatic method [1], and then determine a linear map from the field map using a maximum likelihood estimator with weights proportional to the image intensity [3]. Before we start introducing how we improve the computation speed of our algorithm, we first analyze the main computation load for automatic methods. Noll *et al*'s automatic methods need to reconstruct a large number of images with the signals demodulated at different frequencies in order to achieve enough frequency resolution in the field map estimation, which leads to a lot of computation in gridding. The matrix size of all these images has to be same as the final image, and the objective function should be calculated over all of these image matrices, usually in a relatively large summation window in order to avoid spurious minima, which also requires significant computation. When using automatic methods to perform linear off-resonance correction, the computation load can be greatly decreased since now we only need a linear field map. We implement the following strategies to achieve a rapid automatic linear correction without losing effectiveness of automatic methods. First, since a low resolution field map is sufficient to estimate a linear map, we can use a much smaller matrix for images reconstructed at various demodulation frequencies, which saves a lot of computation on both gridding and objective function calculation. We can use the signals in only the low frequency region in k-space to reconstruct these low resolution images. Using the signals in the low-frequency region not only decreases the computation time of gridding, but also decreases the chance of landing in a spurious minimum of the objective function, since the signal in the low frequency k-space region receives less off-resonance phase accrual. Second, since a linear field map does not need frequency resolution as high as a full field map, we can use substantially fewer demodulation frequencies to estimate the field map. All our experiments show that, given a certain range of off-resonance frequencies, the linear map estimation is insensitive to the number of demodulation frequencies used in the field map estimation. Figure 1 shows the estimated linear map for 7 different real datasets. The off-resonance range is from -150 Hz to 150 Hz. The estimated linear maps show very little variation when the number of demodulation frequencies decreases from 70 to 20. The average standard deviation for the center frequency, X gradient, and Y gradient are only 0.3 Hz, 0.002 Hz/Pixel, and 0.002 Hz/Pixel, respectively. To further speed up the algorithm, we improved the method for calculating the objective function. The objective function at a certain pixel is a summation of a kernel function within a large window around that pixel. For two adjacent pixels, most of their summation windows are overlapped. Therefore, we can calculate one objective function from the other by subtracting one old column and adding one new one. After implementing all these strategies, we achieve an automatic linear correction method with computation speed about 1.7 to 2.5 times that of gridding, depending on how many demodulation frequencies we used.

Results and Discussion: We applied our algorithm to datasets acquired by both gradient-echo and spin-echo spiral scan with good deblurring. The results shown here 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 spectral-spatial pulse was used to suppress the fat. The readout for each slice was done with 14 interleaved spirals each of 16.38 ms readout duration. The samples within the first 3 ms of the readouts were used to estimate the low resolution field map. The incidental phase was removed before calculating the objective function. The reconstructed image matrix was 512 by 512 and the low resolution image matrix was 64 by 64. We used 20 demodulation frequencies with an off-resonance frequency range from -150Hz to 150 Hz. For comparison, we also show the deblurring result using map-based linear correction. It has comparable deblurring to automatic linear correction in this example.

Conclusion: We developed a fast automatic linear off-resonance correction method, which performs linear off-resonance correction without acquiring extra field map datasets. Because it is an automatic method, no additional field map acquisitions are required, which is especially advantageous for dynamic imaging and for hyperpolarized gas imaging. This method is likely to be more robust than pixel-by-pixel automatic methods, although less accurate when the field variation is not linear. Unlike other automatic methods, this method requires a modest amount of computation (2 times gridding), so it is suitable for real-time image reconstruction.

References

[1] Noll et al MRM25: 319-333 (1992) [2] Man et al. MRM 37: 906-913 (1997) [3] Irarrazabal et al. MRM 35: 278-282 (1996)

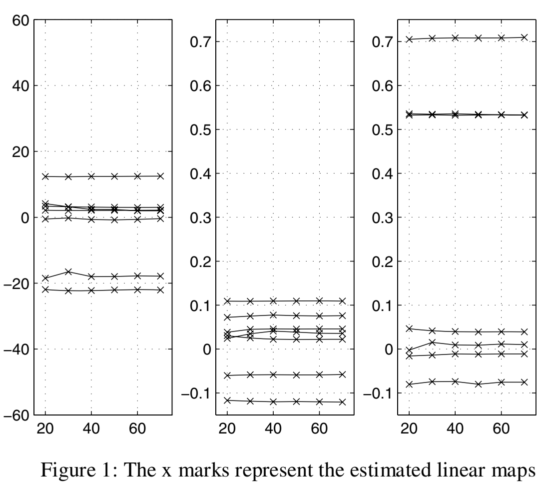

Figure 1: The x marks represent the estimated linear maps as a function of the number of demodulation frequencies used in automatic field map estimation. Left, middle, and right panel show the center frequency (Hz), the X gradient (Hz/pixel), and the Y gradient (Hz/pixel), respectively. The horizontal axis is the number of demodulation frequencies. There are seven linear maps shown, which were estimated from seven different datasets. The off-resonance frequency range is from -150 Hz to 150 Hz.

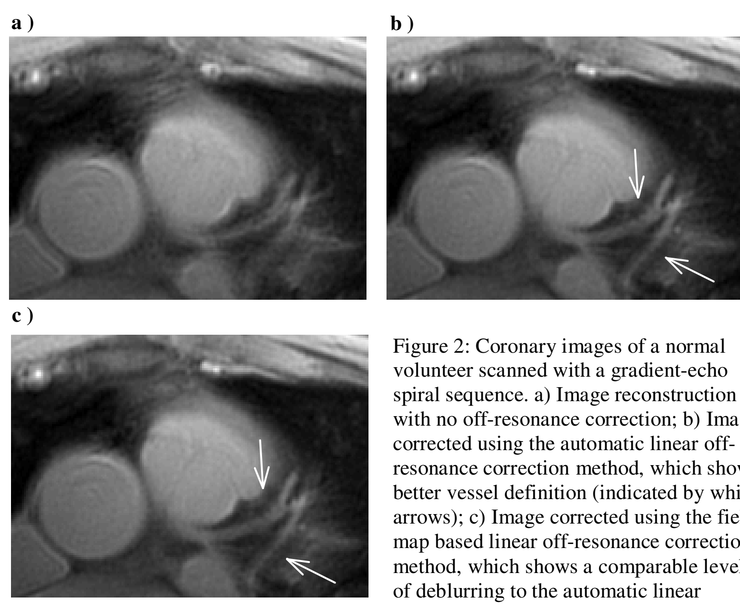

Figure 2: Coronary images of a normal volunteer scanned with a gradient-echo spiral sequence. a) Image reconstruction with no off-resonance correction; b) Image corrected using the automatic linear off-resonance correction method, which shows better vessel definition (indicated by white arrows); c) Image corrected using the field map based linear off-resonance correction method, which shows a comparable level of deblurring to the automatic linear correction.