An auto-focusing off-resonance correction method and its application to dynamic ^{3}He imaging of the lung

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Introduction: For non-2DFT data acquisition such as spiral scanning, image blurring occurs when there is field inhomogeneity. A constant center frequency correction can often obviously improve the image quality [1]. In this abstract, we propose an efficient auto-focusing method to estimate the constant frequency that can best focus the magnitude image. Compared to the other existing auto-focusing methods [2, 3], our algorithm has the advantage that it does not rely on any parameter that has to be decided through trial-and-error. An application of this method is to track the bulk field inhomogeneity shift during dynamic hyperpolarized ^{3}He imaging of the lung.

Methods: Since image blurring can make a magnitude image more homogeneous, which decreases its variance, we can find the constant frequency that best focuses the image by maximizing the variance of the magnitude image. We refer to this constant frequency as the center focusing frequency. When demodulating the signal by a set of frequencies and then reconstructing images from the demodulated signal, we have found that the variance of the magnitude image usually monotonically decreases when the distance between the demodulation frequency and the center focusing frequency increases. This property enables us to use fast numerical search methods to locate the center focusing frequency. To save computation time, we perform demodulation on the gridded data rather than the raw data [3].

In dynamic lung imaging, changes in resonance frequency can arise from respiration. Our method can be used to reduce this effect. The center focusing frequency can be easily obtained from the image itself and it reflects the bulk field inhomogeneity. Therefore, by calculating the change of the center focusing frequency as a function of time, we can track the bulk field inhomogeneity shift during dynamic imaging.

Results: We applied our algorithm to *in vivo* dynamic hyperpolarized ^{3}He lung imaging. For hyperpolarized gas imaging, it is undesirable to collect extra data to estimate a field map or even a spectrum, because this consumes a portion of the hyperpolarized magnetization and thus reduces the signal available for imaging acquisitions. Therefore, auto-focusing methods are preferred for off-resonance correction. We acquired dynamic ^{3}He lung imaging data on a 1.5T Sonata scanner (Siemens Medical Solutions). The spiral sequence used is similar to that developed by Salerno et al [4], but is able to achieve higher spatial resolution by using stronger gradients. The temporal resolution is 133 ms and the nominal spatial resolution is 2.7 mm. Each frame is reconstructed from 20 spiral interleaves with a 3.4 ms data-sampling window. We used a Kaiser-Bessel window with a width of 3 samples for gridding, a 1X grid and a matrix size of 256x256 for reconstruction. We implemented our algorithm in Matlab 7.0 (The MathWorks, Inc). Figure 1 shows a typical frame before and after off-resonance correction using our method. Notice the obvious image deblurring after correction, resulting in improved depiction of the trachea and main bronchi, and better definition of the lung borders.

To study how the center frequency varies during dynamic imaging, we plot the center focusing frequency vs. time in Figure 2. The subject gradually inhaled hyperpolarized gas during the time period shown. The center focusing frequency varied significantly during the scan, with a range of 57.9 Hz, a standard deviation of 12.9 Hz and a positive trend.

Discussion: Our algorithm does not need extra parameters to calculate the objective function. In contrast, the other existing automatic methods rely on tunable parameters to calculate the objective function, e.g. the power of the imaginary image and the cutoff frequency of the low pass filter [2, 3]. The appropriate parameters can vary for different problems and must be estimated by trial-and-error.

One desirable property of our objective function is that it is monotonic. The further the demodulation frequency is from the center focusing frequency, the more blurred the magnitude image becomes. While this seems intuitive and has been true for every data set that we have examined, it is not obvious how to prove that it will be true for all data sets. If this property breaks down, the fast numerical search will be inapplicable and we will have to demodulate the signal by a set of frequencies and choose the one that corresponds to the minimal objective function.

The center focusing frequency is estimated from the whole image. Consequently, sometimes the image quality can decrease in some area after the off-resonance correction compared to before the correction. If we are especially interested in a local area of the image, we can calculate our objective function within a window around that area. In this case, it is important to use care when choosing the size of the window. Spurious minima will arise if the window is too small.

References

[1] Irarrazabal et al MRM 35: 278-282 (1996)
[2] Noll et al MRM25: 319-333 (1992)
[3] Man et al. MRM 37: 906-913 (1997)
[4] Salerno et al MRM 46: 667-677 (2001)

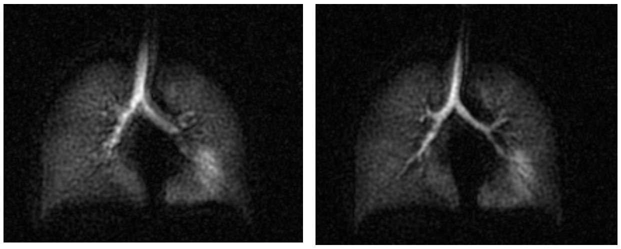

Figure 1: A typical frame from dynamic hyperpolarized ^{3}He lung imaging before (left) and after (right) applying our off-resonance correction method.

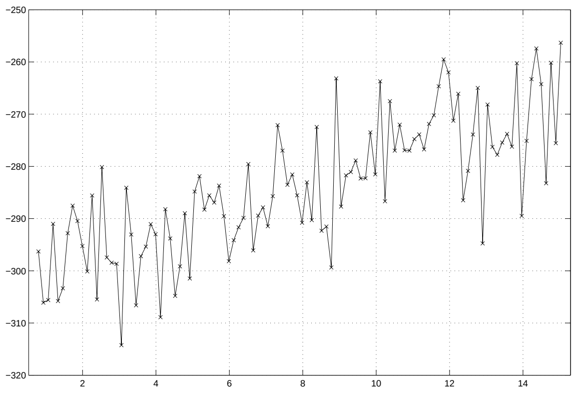

Figure 2: The variation of the center focusing frequency during dynamic hyperpolarized ^{3}He lung imaging. The horizontal axis is the time (second); the vertical axis is the center focusing frequency (Hz).