On-line deblurring in spiral imaging

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Introduction

Spiral MRI is one of the most efficient k-space sampling schemes for fast dynamic image acquisition. The central portion of k-space is frequently updated with each new spiral interleaf allowing the tracking of fast contrast changes. Furthermore it is insensitive against flow effects [1]. In addition, the spiral pattern utilizes the gradient system very efficiently due to its sinusoidal gradient shapes. However, one of the main disadvantages of spiral imaging are blurring artifacts due to off-resonance effects. To estimate local offset frequencies, direct measurement of a field map was proposed [2], which requires additional measurement time. An alternative strategy of deblurring estimates the field map from the data itself [3]. Until recently, these computationally intensive correction algorithms were mainly applied off-line, which delays diagnosis and complicates data handling. In this work, on-line deblurring postprocessing is demonstrated. Its benefit compared to uncorrected reconstruction is shown.

Methods

Acquisition

The measurements were performed on a 1.5 T whole-body scanner (Symphony, Siemens Medical Solutions, Erlangen, Germany) equipped with Siemens Quantum gradients (maximum slew rate 100 $Tm^{-1}s^{-1}$, maximum gradient strength 30 mTm^{-1}). The k-space readout pattern consists of a conventional 3D partition encoding and a spiral in-plane readout with 32 spiral interleaves. For each spiral interleaf, 2048 data points are sampled with a receiver bandwidth of 122 Hz/pixel resulting in a readout time of 8 ms. The in-plane resolution is 0.84 x 0.84 mm^2, whereas the thickness of the 3D partitions is 1 mm. The other sequence parameters are: FOV=230 mm, 20° TONE RF pulse, TE=1.8 ms, TR=15 ms.

On-line processing

Data gridding and reconstruction (according to [4]), as well as an on-line postprocessing deblurring algorithm were implemented for the standard image reconstruction environment (CPU clock rate: 1.7 GHz) of the scanner. Immediately after the measurement the corrected images are available in the patient database of the MR scanner. In the deblurring algorithm [3] images are reconstructed at different offsets from the resonance frequency. The imaginary part of the reconstructed image is then minimized for each spatial point over an integration window. In our measurements we modulate the reconstruction frequency in steps of 10 Hz in an interval from –80 to 200 Hz whereas the integration window is 32x32 pixel. For regridding, the data is twofold oversampled, which implies a fourfold memory load and computation time.

Results

The processing time of the deblurring algorithm depends on the matrix size and the number of off-resonance frequency steps. For a matrix size of 320x320 the time for reconstruction and deblurring of one partition is approximately 40 s. Fig. 1 shows the results of a phantom experiment. Susceptibility changes at the boundaries between water, perspex and air cause strong blurring (Fig. 1.a.). This can be corrected for by the on-line deblurring (Fig. 1.b.). Fig. 2 shows maximum intensity projections (MIP) of a spiral time-of-flight cerebral angiography of a healthy volunteer. With two averages, the total measurement time was 70 s. The in-vivo uncorrected data set shows blurring artifacts (Fig. 2.a.). These artifacts are removed by the on-line deblurring algorithm thus increasing visibility of small vessels in regions of high field inhomogeneity (arrows in Fig. 2.b.).

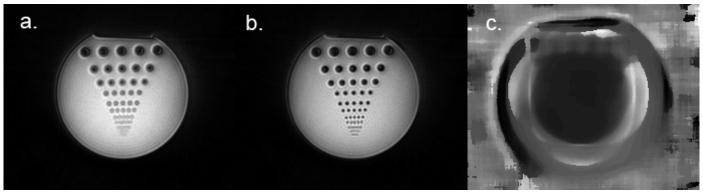

Fig 1. Spiral images of a resolution phantom: a. uncorrected image, b. deblurred image, c. calculated fieldmap showing optimal offset reconstruction frequency.

Discussion

The implemented algorithm significantly increases image quality of spiral data acquisition. Additionally, it provides prompt access to the images allowing immediate medical diagnosis and easy handling in existing databases.

An upgrade to a more powerful CPU of the image processor would further reduce postprocessing time. Algorithmic optimizations, e.g. spare out the oversampled regions outside the FOV after Fourier transformation, will open more options for on-line or even real-time data processing. Thereby sequences with spiral and other non-rectilinear sampling patterns could become more widely used in clinical routine benefitting from their inherent efficiency.

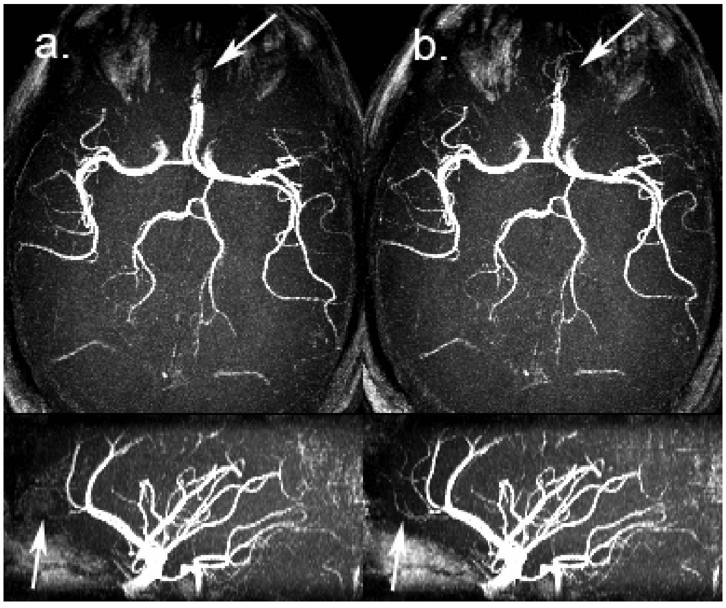

Fig. 2. On-line deblurring in spiral time-of-flight angiography: a. uncorrected MIP, b. MIP of deblurred data. The region with high susceptibility changes (arrows) benefits noticeably from the correction.

References

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