Magnetic Field Monitored Autofocus Deblurring for Improved Non-Cartesian Imaging

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INTRODUCTION: Non-Cartesian data acquisition schemes, which traverse large portions of k-space within a single excitation (e.g. spiral, radial, etc.), promise a number of important advantages, including increased data acquisition efficiency and reduced sensitivity to motion. Practical usage of such advanced data acquisitions schemes, is often limited by ΔB_0 related artifacts (i.e. blurring, ghosting, geometric distortions, etc.), and gradient field imperfections (i.e. Eddy currents, concomitant fields, group delays, etc.). These problems are typically addressed by, 1) careful system calibration in form of B_0-shimming and gradient characterization, and/or 2) at the reconstruction stage by incorporating additional information in form of ΔB_0 maps [1-4], and actually measured k-space trajectory information [5-8]. Generally, those system tuning and calibration steps require extra scan time and experienced user interaction to be successful.

In this work an autofocus reconstruction is introduced, similar to the one described by Noll et al [9], which achieves automatic deblurring without prior information on ΔB_0. In order to also account for gradient field imperfections, magnetic field monitoring (MFM) has been used to capture the exact encoding information simultaneous to data acquisition [6,8,10]. Hence, high-quality spiral images were obtained in the presence of significant ΔB_0 inhomogeneities and gradient field imperfections, without the need for extra system tuning, or calibration interactions.

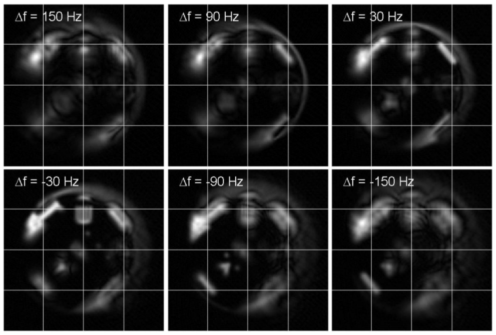

Fig. 1: Reconstruction for different off-resonance frequencies.

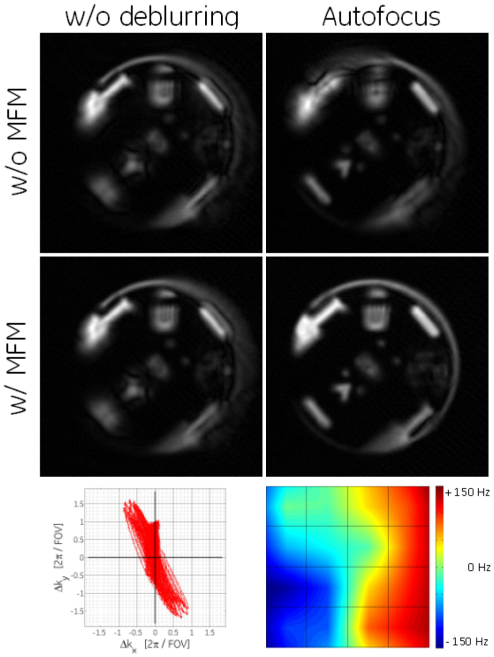

Fig. 2: Phantom images demonstrating the effectiveness of autofocus ΔB_0 deblurring in combination with MFM.

METHODS: The proposed autofocus deblurring reconstruction is based on the following two step procedure: First, a low resolution off-resonance map is automatically determined from the application of an autofocus criterion to a series of base images reconstructed to different off-resonance frequencies. Second, a conjugate-gradient (CG), multi-frequency interpolation (MFI) reconstruction [2,4] is used for image reconstruction with the autofocus obtained off-resonance map incorporated. For the first step, the set of base images $\{\text{image}_{\Delta f}\}$ is obtained by reconstructing the measured data to different off-resonance frequencies, $\Delta f=\gamma\Delta B_0$, according to:

$$\text{image}_{\Delta f}(\mathbf{r}) = \int \text{data}(\mathbf{k}) * e^{-i\mathbf{kr}} * e^{-i2\pi\Delta f(T_E+t(\mathbf{k}))} * d\mathbf{k} = \text{image}_{\Delta f=0}(\mathbf{r}) \otimes \text{FT}\left(e^{-i2\pi\Delta f(T_E+t(\mathbf{k}))}\right), \quad (1)$$

with T_E denoting the echo time. The obtained images are then divided into N_1 x N_2 smaller segments, and for each of those segments a local off-resonance value is automatically determined based on the maximization of a regional signal intensity based focus measure. The obtained low-resolution off-resonance map is interpolated to the desired image resolution and subsequently reconstructed using a CG-MFI algorithm [4]. For efficient computation, the set of base images $\{\text{image}_{\Delta f}\}$ (1) can be reused in the CG-MFI reconstruction. Physically, the regional signal-intensity based autofocus criterion is motivated by the observation of signal intensity reduction due to off-resonance in-plane dephasing. Because of the spatial extend of blurred point spread function (PSF) this autofocus criterion is of approximate nature only.

In order to account for gradient field imperfections, MFM has been applied to monitor the actual image encoding [8,10]. Therefore, the imaging object is surrounded by small NMR probes acting as local magnetic field sensors, which permit accurate k-space trajectory measurements simultaneous to data acquisition. CG-MFI image reconstruction is then performed based on the actually applied k-space sampling, rather then the nominal assumed one. Imaging experiments were performed on a GE Signa Excite 3T system (GE Healthcare, Milwaukee, WI) using an 8-channel receive head array and the standard GE resolution phantom.

RESULTS: Figure 1 shows 6 (out of 41) base images $\{\text{image}_{\Delta f}\}$ of a spiral dataset (4arms, 8192pts, FOV=0.3m, BW=±62.5kHz) reconstructed to different off-resonance frequencies between –150Hz and +150Hz. Different regions of the image get focused at different off-resonance frequencies. The application of the autofocus criterion to 8x8 smaller imaging regions results in a low-resolution off-resonance map, which was fitted and interpolated to the original image resolution of 256x256. Subsequently, CG-MFI image reconstruction was performed with the Δf map incorporated.

Figure 2 illustrates the improvements achieved by using MFM, as opposed to performing image reconstruction based on the erroneous nominal k-space trajectory. The deviation between the nominal and the MFM-measured k-space trajectory was found to be in the order of about one k-space point (lower left plot in Fig. 2). Notably, the performance of the autofocus algorithm was found to crucially depend on accurate k-space encoding information (cf. middle row Fig. 2). This is related to the fact that gradient encoding imperfections result in additional blurring, which causes the autofocus criterion to flatten and fail. Appreciable signal intensity variation across the image is explained by using only one element of an 8-element whole-body transmit array for signal excitation.

DISCUSSION and CONCLUSIONS: In the present work a simple and computationally efficient autofocus off-resonance deblurring reconstruction has been described. In combination with MFM the method was found to work robust for smooth ΔB_0 variations up to several hundreds Hz. The method was demonstrated for a resolution phantom, which because of it's spare image structure constitutes a demanding test case for ΔB_0 mapping based deblurring algorithms. Without relying on a separately acquired ΔB_0 field map the autofocus reconstruction in combination with MFM was demonstrated to result in high-quality spiral images. Without major modification the autofocus method can also be combined with parallel imaging.

REFERENCES: [1] Noll DC, et al, IEEE TM 10: 629 (1991), [2] Man LC, et al, MRM 37: 785 (1997), [3] Sutton BP, et al, IEEE TM 22: 178 (2003), [4] Barmet C, et al 13th ISMRM 2005, p682, [5] Duyn JH, et al, JMR 132: 150 (1998), [6] Mason GF, et al, MRM 38: 492 (1997), [7] Takahashi A, et al, MRM 34: 446 (1995),), [8] Pruessmann KP, et al, 13th ISMRM 2005: 681, [9] Noll DC, et al, MRM 25: 319 (1992 [10] Sipilae P, et al, 15th ISMRM 2007: 3277.