# Efficient Off-resonance Corrected Reconstruction of Rosette Trajectories by Deformed Interpolation Kernels

M. Reisert[1], J. Hennig[1], T. Grotz[1], and B. Zahneisen[1]
[1]Medical Physics, University Hospital Freiburg, Freiburg, Baden-Wuerttemberg, Germany

**Introduction:** With the use of multiple localized, small receive coil arrays, single shot whole brain coverage becomes feasible for fMRI applications. Using a 3D rosette trajectory and iterative, regularized reconstruction a $64^3$ volume can be acquired in less than 30ms with acceptable broadening of the point spread function (1). Single shot trajectories suffer from off-resonance effects because of their long readout times that causes severe spin dephasing. For the case of trajectories with intersections in k-space (radial, rosette), this leads to signal cancellations. Therefore it is important to take the phase evolution into account during the reconstruction process. Common approaches approximate the phase map by a time segmentation to correct for these effects (2) but slow down the reconstruction by the number of time segments, arriving at multiple days for the reconstruction of one sequence. We therefore have developed an off-resonance correction approach, which uses an approximation in space by deforming k-space interpolation kernels, which leads to a speed up of a factor of 10 at comparable or even improved reconstruction quality.

**Methods:** Iterative reconstruction methods model the measurement process (as in equation [1]) and aim to minimize the differences between the generated and acquired data. For non-Cartesian trajectories the *nuFFT* [1] is usually employed to provide an efficient implementation of the signal equation. Equation [2] and Figure 1 demonstrate the usual approach: the spin density is multiplied by the coil sensitivities, transformed into k-space, and then projected onto sparse interpolation kernels (e.g. minmax-interpolation [1]) providing the evaluation at non-grid points in k-space. To incorporate off-resonance the common way is to use a time segmentation (1) of the phasemap. The complexity of this approach scales with the number of time segments, which is in certain cases unacceptable. Our new approach is driven by the observation that most of the reconstruction time is spent for the *FFT* while only 5% is used for the evaluation of the *nuFFT*-interpolation kernels. Thus, our idea is to directly incorporate the phase map into the interpolation kernels. Due to the convolution theorem the phasemap corrections in real-space translate to convolutions in k-space of the Fourier transformed phasemaps with the *nuFFT*-interpolation kernels (equation [3]). These convolutions can be accomplished prior to reconstruction. These new 'deformed' kernels are less sparse, but due to the nature of the phase maps (no changes in magnitude) they are still sufficiently sparse. The computation is depicted in Figure 2. After multiplication with the phasemaps the kernels are transformed back into k-space and sparsified by a thresholding operation. To avoid ringing artefacts typically caused by thresholding in k-space the field map is smoothed before.

$$s_n(t) = \int \rho(\vec{r}) C_n(\vec{r}) e^{-i\omega(\vec{r})t} e^{-i\vec{k}(t)\vec{r}} d\vec{r} \qquad (1)$$

$$s_n(t) = \sum_{i,j,m} \mathrm{FFT}(C_n \cdot \rho)_{i,j,m} \; K(\vec{k}(t))_{i,j,m} \qquad (2)$$

$$s_n(t) = \sum_{i,j,m} \mathrm{FFT}(C_n \cdot \rho)_{i,j,m} \; [\mathrm{FFT}(e^{-i\omega(\vec{r})t}) * K(\vec{k}(t))]_{i,j,m} \qquad (3)$$

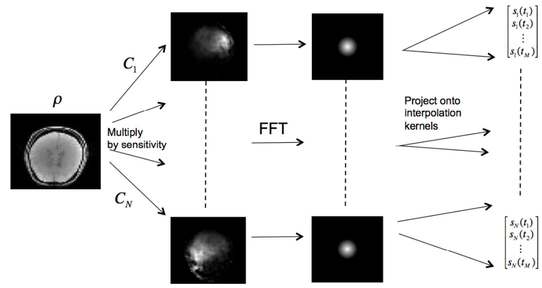



**Fig. 1: The implementation of the forward operator**.

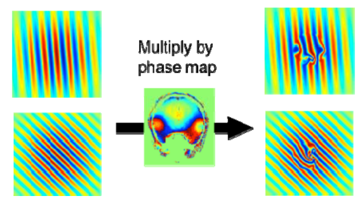
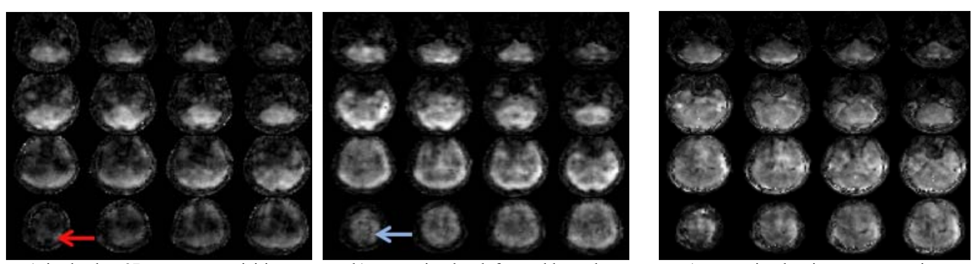


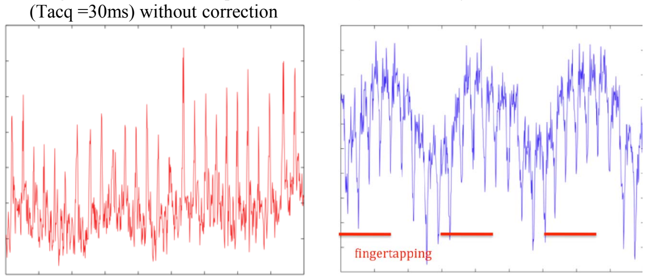

**Fig. 2 Construction of the deformed interpolation kernels.**

**Results:** All measurements were performed on a Tim Trio using a commercial 32-channel head coil array (Siemens, Erlangen). The rosette trajectory consists of 40 petals that are designed to provide homogenous k-space coverage (fov =256mm, res=$64^3$). A static field map was derived from a 3D double gradient echo measurement by subtracting the phase images of the two consecutive echos. In Figure 3 reconstructions a) without correction, b) with corrections by our new approach and c) by time segmentation are shown. Our results are comparable to the time segmentation approach at 10 times faster reconstruction speed. Our results look somewhat smoother than the time segmentations. Overall, the corrected reconstructions yield significantly more signal compared to the uncorrected reconstruction. Figure 3 d) and e) show the time course within a single voxel (arrows in a) and b)) in the motor cortex which is usually affected by off-resonance effects. The stimulus depend signal changes are much more apparent in the corrected signal.

**Conclusion and Outlook:** We proposed an efficient method to correct for off-resonance caused signal-cancellations by a simple preprocessing of the interpolation kernel, which appear inside the common *nuFFT*. This leads to a speed up by a factor of 10 in comparison to the traditional approach based on time segmentation. Preliminary comparisons in image quality suggest that our approach is even more accurate, but further and more rigorous investigations are necessary to compare the performance of both approaches. Both, deformed kernels and times segmentations are approximations to the real signal equation, the first one in space the latter in the time (k)-domain. In situations like ours where the FFT is the bottleneck during reconstruction and computation time is a critical issue our method appears preferable. Comparison of robustness and artefact behaviour require more detailed studies both in simulations as well as on experimental data. Our approach has been demonstrated to Rosette trajectories but can be easily extended and applied for other and arbitrary k-space trajectories.



a)single shot 3D rosette acquisition (Tacq =30ms) without correction  b) correction by deformed kernel  c) correction by time segmentation




d) single voxel time course without correction  e) finger tapping time seriescorrection by deformed kernel

**Fig. 3 Results.** Comparison of the proposed approach b) with the standard approach c) on a finger tapping fMRI sequence. In subfigure d),e) the signal time course of a single voxel in the motor cortex which is strongly affected by field distortions is shown.

**References** 1. B. Zahneisen, et al, Proc. 16th Ann Meeting ISMRM, Honolulu, 2008, p. 3669
2. B. P. Sutton, C. Noll and J. A. Fessler, *Fast, iterative image reconstruction for MRI in the presence of field inhomogeneities,* IEEE Trans. Med. Imaging, 2003, vol. 22, no.2, pp. 178-188

**Acknowledgements:** This work is part of the INUMAC project, supported by BMBF (German Federal Ministry of Education and Research), grant #13N9208 and part of the OVOC project, ERC Advanced Grant #23290.