Off-resonance effects in non-Cartesian parallel imaging

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Introduction: Off-resonance commonly exists in MR systems and can cause image artifacts in a number of MR imaging methods. MR scanning based on non-Cartesian sampling in k-space is sensitive to off-resonance. Off-resonance effects and their correction have been widely discussed in full FOV non-Cartesian sampling methods [1]. Off-resonance effects on non-Cartesian parallel imaging are more complicated than with full FOV acquisition since they not only cause image blurring but can also interact with the unaliasing process. In this abstract, we use spiral scanning as an example to demonstrate the off-resonance effects on non-Cartesian parallel imaging.

Theory and Results: The off-resonance term breaks down the Fourier relationship between imaging object and acquired k-space signal. Residual aliasing can occur in SENSE reconstruction under the influence of off-resonance [2, 3]. A concatenation of unaliasing and off-resonance correction fails in SENSE reconstruction [3]. By introducing the off-resonance term into the encoding matrix, Barmet et al reported a SENSE type iterative reconstruction algorithm for simultaneous unaliasing and off-resonance correction in parallel imaging [3].

Off-resonance effects on k-space based parallel imaging methods, such as BOSCO [4], can be quite different. The unaliasing process in BOSCO is insensitive to off-resonance as long as the training target (fully sampled low frequency data used to estimate the BOSCO kernels) and the training source (undersampled low frequency data) have similar off-resonance point spread functions (PSFs). For example, this is true in dual-density spiral acquisitions, where training data is acquired during the first part of each spiral readout. Consequently, for dual-density spiral sampling, off-resonance correction can be applied after unaliasing to remove blurring artifacts. The explanation for this is that the BOSCO kernels used for unaliasing are derived by optimized fitting to a blurred but full FOV data set. Figure 1 is a simulation example to demonstrate this phenomenon.

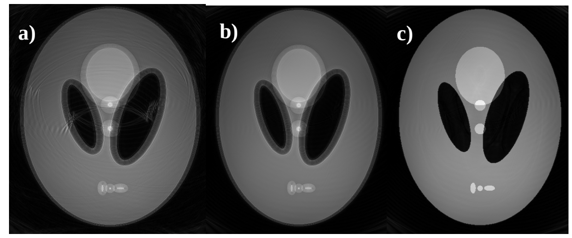

Figure 1: Simulation of 2X accelerated dual density spiral with off-resonance map varying from 40 to 290Hz. a) Gridding; b) BOSCO, there is only blurring and no residual aliasing after BOSCO; c) BOSCO with additional off-resonance correction removes blurring artifacts

The off-resonance effects become more complicated in BOSCO reconstructions when the PSFs differ significantly between the training target and the training source. This is the case in constant density spiral acquisitions when a single shot full FOV spiral is acquired for training. The asymmetry between the training target and the training source can cause inaccuracy of the BOSCO kernels and result in residual aliasing artifacts. To address this problem, off-resonance correction can be applied to correct the PSFs of the training target and that of the training source before the training process. Conjugate phase reconstruction and its approximations [5] can be used to correct the off-resonance effect on the aliased training source since these methods deblur both the center lobe and the side lobes in the under-sampled PSFs. Figures 2 and 3 demonstrate the off-resonance effect on BOSCO reconstruction and its correction using a 2X accelerated constant density spiral when a full FOV single shot spiral is used as the training target.

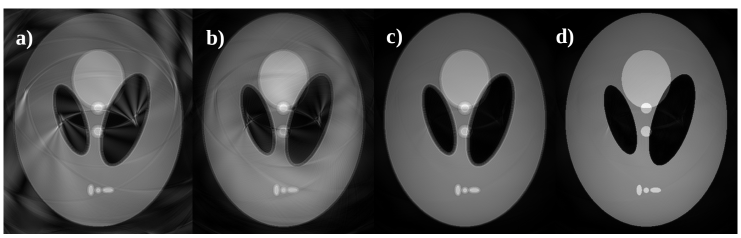

Figure 2: Simulation of 2X accelerated constant density spiral with an off-resonance map range from 10 to 70 Hz. a) Gridding; b) After BOSCO reconstruction. Residual aliasing is obvious after BOSCO due to asymmetric training; c) BOSCO with off-resonance correction applied to training removes residual aliasing; d) BSOCO with off-resonance correction applied to both training and deblurring removes both residual aliasing and blurring

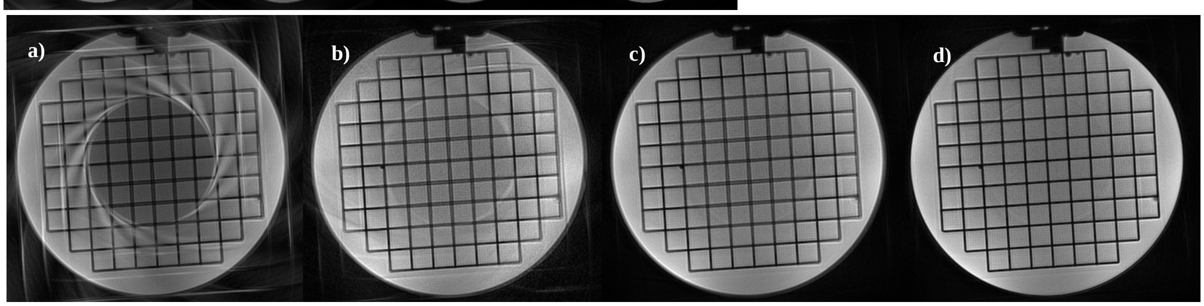

Figure 3: A phantom data set acquired by 2X accelerated constant density spiral scanning from a Siemens 1.5T Avanto scanner. The measured off-resonance map ranges from -30 to 50 Hz. a) Gridding; b) After BOSCO reconstruction. Residual aliasing is obvious after BOSCO due to asymmetric training; c) BOSCO with off-resonance correction applied to training removes residual aliasing; d) BSOCO with off-resonance correction applied to both training and deblurring removes both residual aliasing and blurring

Discussion and Conclusion: Off-resonance can interfere with unaliasing in non-Cartesian parallel imaging, in addition to causing image blurring as in non-parallel imaging. For BOSCO k-space-based reconstruction methods, maintaining consistency between the training source and the training target is the preferred method of preventing the degradation of unaliasing in the presence of off-resonance. Inconsistency between the PSFs of the training source and the training target can be corrected using existing off-resonance correction methods, but these methods may be hindered by the difficulty of acquiring an accurate field map. Off-resonance correction using BOSCO is less computationally demanding and memory intensive than with SENSE reconstruction methods. Off-resonance effects on kSPA [6] are currently under investigation. This study focused on off-resonance effects in non-Cartesian parallel imaging, but similar effects from short T2* decay are observed in our simulations.

References: [1] Noll et al MRM 25: 315 (1992) [2] Pruessmann et al MRM 46: 638 (2001) [3] Barmet et al Proceedings 13th ISMRM, 682 (2005) [4] Hu et al, Proceedings 14th ISMRM, 10 (2006) [5] Macovski A MRM 2: 29 (1985) [6] Liu et al Proceedings 15th ISMRM, 332 (2007)