Instant Measurement of Point Spread Functions Using an NMR field probe

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Introduction

The point spread function (PSF) is a versatile tool for characterizing the image reconstruction process. By definition, the PSF describes how signal from a point source is mapped onto the pixels in the image-domain matrix. The comprehension and detection of artifacts as well as image characteristics such as FOV and resolution is greatly advanced by this concept. In order for signal to propagate from an object point source to image pixels, both signal encoding and image reconstruction must be performed. Commonly PSFs are simulated assuming a nominal k-space trajectory; confounds such as concomitant fields or eddy currents of various spatial order are rarely taken into account. Moreover the image reconstruction steps performed by commercial scanners are hardly accessible. For these reasons it would be advantageous to directly measure the PSF of a certain scan, rather than computing it based on uncertain assumptions. In this work, the PSF is directly measured using a transmit/receive NMR field probe which represents the point source. PSFs are investigated for spiral and EPI scans in different imaging setups.

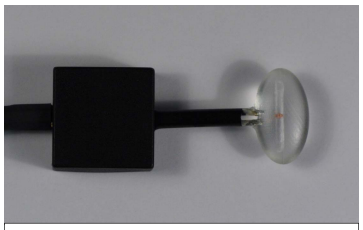

Fig. 1: An NMR field probe Used as Proton Density Point Source For PSF Measurements.

Methods

The point spread function is defined as the mapping of an ideal Dirac point source in object space onto the pixels of the prescribed reconstruction matrix. This refers to the columns of the combined encoding and reconstruction matrix, E and F, respectively, in an algebraic formulation of the MR reconstruction problem $i = F \cdot E \cdot m = F \cdot d$ (1) with i being the image matrix, m the spatial distribution of object magnetization, and d the data vector [1]. Thus, only if the full information about the acquisition and reconstruction process is known, a simulation of the PSF via (1) is possible by setting $d = (1, \dots, 1)^T \in \mathbb{R}^N$ (N = number of data points). If the exact encoding scheme is unknown, the PSF can be inferred from a measured approximate point source in object space. A susceptibility-matched ^{1}H NMR field probe [2] was used: H_2O doped with $CuSO_4$, 0.7 mm diameter, T_2*=80ms. The probe was excited using the body coil. Compared to measuring a small water droplet in a typical object by a standard coil, the sensitivity is greatly enhanced using an NMR field probe due to the vicinity of the solenoid to the signal source. All scans were performed on a Philips Achieva 3T system (Philips, Best, NL).

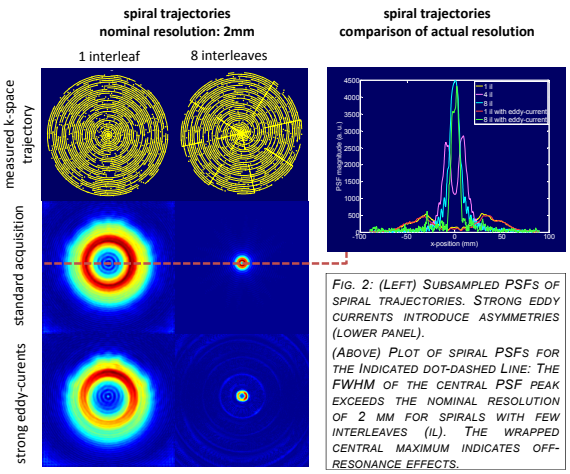

Fig. 2: (Left) Subsampled PSFs of spiral trajectories. Strong eddy currents introduce asymmetries (lower panel). (Above) Plot of spiral PSFs for the indicated dot-dashed line: The FWHM of the central PSF peak exceeds the nominal resolution of 2 mm for spirals with few interleaves (il). The wrapped central maximum indicates off-resonance effects.

The PSF measurements are presented in 2 variants: (1) treating the whole MR scanner as a black box and investigating the final image of the NMR field probe with the inherent matrix resolution. In this way, artifacts can be detected on a coarser scale. (2) By reconstruction of several datasets with different shifts of the field of view (FOV) in a sub-resolution range. Thereby one can create a finer, subsampled depiction of the PSF by interleaving the final reconstructions to form a larger PSF matrix. This subsampling approach does not require additional measurements, if the reconstruction framework is accessible and reconstructions with different FOVs can be executed. Highly subsampled PSFs then allow for a quantitative evaluation of image properties: actual resolutions of different acquisition schemes may be compared via the FWHM of the main lobe of the corresponding PSFs. The gradient evolution and higher order field fluctuations were monitored using a 3rd order concurrent monitoring setup, based on 16-^{19}F-NMR field probes [3]. The method was applied to EPI and spiral trajectories for a variety of imaging parameters (readout duration/no. of interleaves, resolution 1-2.5 mm). It was compared to standard reconstruction in intricate imaging situations that were provoked by deliberately disabling the eddy current correction and including a strong diffusion gradient just before acquisition.

Results

For the spiral acquisitions the subsampled PSFs exhibit obvious blurring related to B_0 off-resonance for a variety of measured spiral trajectories (Fig. 2). As expected the effects increase with longer readouts (less interleaves). A plot of the central PSF row for these reconstructions confirms a resolution loss of several multiples of the resolution. For the EPIs and a coarse PSF depiction (variant 1), undersampling artifacts in the SENSE reconstruction are visible as well as ghosting for the single-shot EPI by replications of the central PSF lobe (Fig. 3). Furthermore, non steady-state excitations yielding signal fluctuations for different shots of an interleaved EPI manifest themselves as ghosting artifacts, too.

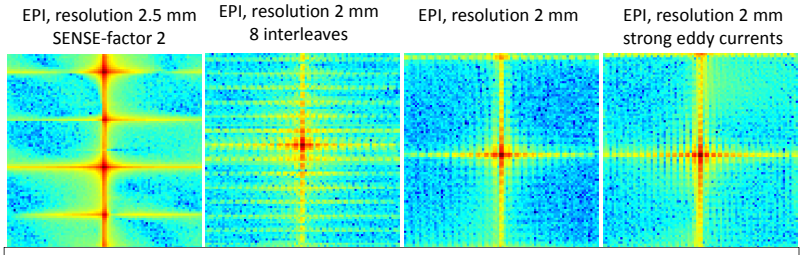

Fig. 3: Coarse PSF measurement of several EPIs using the scanner as black-box (log-plot). Ghosting Artifacts manifest themselves as repetitions of the main lobe of the PSF either via undersampling (left) or multiple excitations with unequal flip angle (2nd left).

Conclusion

Simulations of a correct PSF are often hampered by incomplete knowledge of either the encoding process or image reconstruction. Therefore it might be beneficial to directly measure the PSF, which was proposed by use of a single NMR field probe. Two variants have been presented: either the entire scanner is treated as a black box, or only the signal encoding is considered unknown, while the reconstruction framework is modifiable. Thus, a simple scheme to test MR sequences for imaging artifacts is implemented, as well as a sensitive measure for quantifying fundamental imaging characteristics, such as the actual resolution in individual image pixels.

References [1] Pruessmann, K. NMR in Biomedicine 19 2006. [2]De Zanche et al. MRM. 60, 2008. [3] Barmet et al., Proc. ISMRM. 10, p. 216, 2010.