Point Spread Function Mapping with Parallel Imaging with High Acceleration Factors: Fast Method for EPI Distortion Correction

M. Zaitsev[1], J. Hennig[1], O. Speck[1]
[1]University Hospital of Freiburg, Freiburg, Germany

Introduction

The point spread function (PSF) mapping by constant time imaging technique was introduced by Robson et al.[1] and recently adopted to the distortion correction by Zeng and Constable,[2]. This multi-reference technique enables to correctly map EPI distortions both in regions of low- and high-filed inhomogeneity. The technique is also advantageous, because it is based on the EPI readout, and thus the effects of inherent eddy currents and concomitant gradients are also mapped faithfully.

These further developments to the technique, presented here, are based on the insight, that the full dataset used for the PSF-correction is scarcely populated. This allows to use accelerated k-space acquisition techniques for the PSF encoding with high reduction factors without compromising the accuracy of the reference data. This particular feature of the PSF-reference dataset makes it also especially suitable for implementation with parallel imaging (PI) techniques. In this abstract we demonstrate various possibilities of combining the PSF data acquisition with parallel imaging techniques, such as (i) mapping distortions of PI-enabled EPI, (ii) acceleration the PSF acquisition using PI techniques and (iii) the combination of the above, when distortion of the PI-enabled EPI are mapped with PI-accelerated PSF acquisition.

Methods

The sequence for PSF-mapping is based on the standard EPI readout with a modified phase-encoding pre-winder. The sequence is repeated several times with step-wisely incremented phase encoding gradient to fill the additional *k*-space dimension, referred to hereon as PSF or gradient-echo (GE) dimension. The phase encoding dimension formed by the EPI readout itself is termed hereon EPI dimension. For each slice the PSF-mapping sequence delivers a three-dimensional *k*-space dataset with a single frequency encoding dimension and two independent phase encoding dimensions. The reconstruction of the distortion maps from the *k*-space PSF data requires 3D Fourier transform to be applied. In order to enable PI in ether of the phase encoding dimensions the reconstruction of the missing *k*-space data needs to be placed at certain positions in the reconstruction. In this abstract we demonstrate the possibility of exploiting GRAPPA[3], because it preserves the phase of the complex data and does not intrinsically combine multi-channel data. Although it is not demonstrated here, it is in principle possible to employ other parallel imaging methods as long as they satisfy two conditions: (i) the phase information is to be preserved and (ii) the method must allow to restore separate coil images. The second requirement may, however, be violated if the parallel acquisition is applied only in one phase encoding dimension.

The PSF mapping technique was implemented and tested on two whole-body systems: Siemens Magnetom Sonata 1.5T, Siemens Magnetom Trio 3T (Siemens Medical Systems GmbH). The imagers were equipped with similar gradient systems, capable of 40mT/m gradient strength per axis with minimal rise time of 200µs. Both systems were equipped with 8-channel receive-only coils for head imaging.

Phantom measurements were performed in a spherical phantom filled with water doped with $Ni(NO_3)_2$. *In vivo* imaging experiments were performed in healthy volunteers. All experiments with human subjects were performed in accordance with local IRB regulations; informed consents were obtained prior to measurements. Typical imaging parameters for the PSF mapping sequence were: FoV=224mm, 128^2 2D image matrix, readout bandwidth 1.4kHz/pix, echo spacing 800µs, TE=30ms, TR=3s. GRAPPA reconstruction used 16 reference lines. The measurement sequence and the reconstruction procedures were fully integrated into the scanner software platform. The reconstruction was performed online on the scanner in a fully-automated operator-independent manner[4] and was combined with online motion correction.

Results

Fig. 1 demonstrates the possibility of using PI for acceleration of the PSF acquisition for fully-encoded EPI (left) and 2x-accelerated EPI. Plots in Fig. 1 presents the PSFs in the central image area acquired in the water-filled spherical phantom. Solid lines correspond to GRAPPA PI reconstruction; dotted lines represent the distorted PSFs produced by zero-filling the missing PSF-encoding steps and are provided to visualize the positions and maximum amplitudes of the ghosts. Note that the second graph does not exhibit additional ghosting. The low-intensity broadening of the PSF appears to be characteristic for the GRAPPA reconstruction applied to EPI.

Fig. 2 presents the results of the *in vivo* experiment with PI applied in both EPI and PSF-encoding dimensions. Acceleration factor of 2 was used for EPI combined with the 4x-accelerated acquisition of the PSF encoding. The reconstructed GE image suffers from certain modulation artefacts. These artefacts, however, did not influence the definition of the PSF peak position and thus the accuracy of the pixel shift maps, reconstructed from the data. This results in the high-quality corrected EPI image, displayed in Fig 2, right. It is to be noted, that the "3D" PSF raw data was undersampled here by the factor of 8 (if the acquisition of the reference lines is ignored).

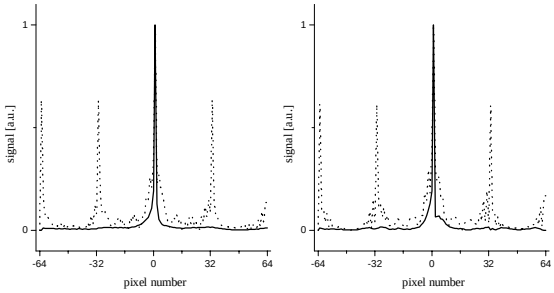

Fig. 1. *Profiles through PSF in the central image region acquired in a spherical water-filled phantom. PSF with GRAPPA reconstruction (solid line) for 4x PI acceleration for the PSF dimension with full EPI acquisition (left) and with 2x-accelerated EPI (right). Dotted lines show PSFs reconstructed without GRAPPA and are given for reference.*

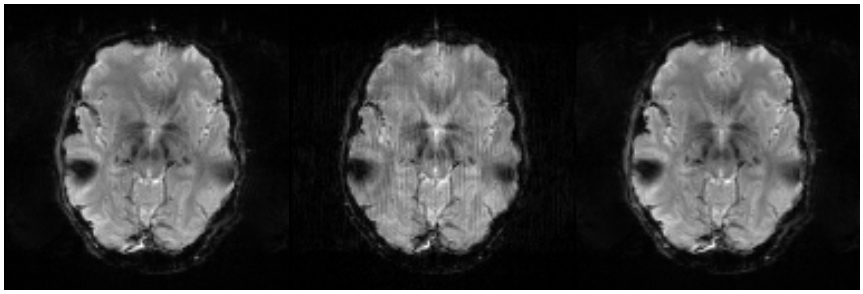

Fig. 2. *Axial brain images acquired with the PSF sequence with 2x EPI acceleration and 4x PSF acceleration. Phase encoding direction is R-L. Distortions in the frontal area are apparent in the EPI image (left). Distortion-free gradient-echo image (middle) reconstructed from the PSF data shows modulation, which, however, does not disturb the appearance of the corrected EPI image (right). Note, that the "3D" PSF data themselves were reconstructed here with only about 1/8th of the fully-sampled data.*

Conclusions

The PSF mapping technique is not only able to map distortions in accelerated EPI acquisitions, but also is able to win significantly from combination with parallel imaging. The specific character of the "3D" PSF data affords extremely high acceleration factors, which may, in principle, exceed the number of receivers in the array.

References

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