Accelerated Point Spread Function Mapping Using Compressed Sensing for EPI Geometric Distortion Correction

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Introduction: Single-shot echo-planar imaging (EPI) is a fast technique allowing the acquisition of an image following a single RF excitation. The high temporal resolution of EPI makes it the method of choice for applications such as fMRI or diffusion tensor imaging. However, EPI is prone to geometric and intensity distortions in the presence of magnetic field inhomogeneities. Several correction techniques have been proposed in the past based on field map acquisitions [1] or point spread function (PSF) acquisitions [2, 3]. Parallel imaging techniques such as GRAPPA were employed for accelerating the PSF data acquisition [4]. In this work we demonstrate that compressed sensing (CS) [5] reconstruction can be used for acquiring the PSF data set with high acceleration factors for accurate geometric distortion corrections.

Theory: CS relies on data sparsity and incoherence of the undersampling artefacts. In the case of Cartesian sampling, incoherence can be achieved by random sampling in the phase-encoding (PE) direction. The CS algorithm is particularly well adapted to the PSF data which is very sparse. Consequently, the use of a sparsifying function is not needed for this particular application. The CS reconstruction is performed using the unconstrained optimization problem:

$$\min \| F_u \cdot x - y \|_2^2 + \lambda \| x \|_1$$

where x represents the PSF data-set, y is the acquired data, F_u the Fourier operator and λ the regularization parameter that determines the trade-off between data consistency and sparsity.

Materials and Methods: Fully sampled PSF data sets of a phantom and a healthy volunteer were acquired on a Magnetom Tim Trio 3T clinical scanner (Siemens Healthcare, Erlangen, Germany). The PSF data is acquired using a GE single-shot EPI sequence with different values of the dephasing gradient in the PE direction. The sequence parameters were TR = 2000 ms, TE = 30 ms, matrix size 64 × 64, FOV = 192 ×192 mm^2, 20 slices with slice thickness 3 mm. Different undersampling factors (5.8-7.5) in the PSF-encoding direction were subsequently simulated by using randomly-distributed PSF encoding steps. Data processing was performed off-line with custom-made software developed in Matlab. The following reconstruction steps were performed: read FT (including linear phase correction), phase FT, CS non-linear reconstruction in the PSF direction using the conjugate gradient method with 80-200 iterations. Consequently, for each EPI image the PSF data has three dimensions: read-direction (X), phase encoding of the EPI image (Y_{EPI}, distorted), and phase encoding of the gradient-echo image (Y_{GE}, non-distorted). The pixel shift maps were derived using a method similar to that proposed in [4], with the difference being that they are calculated in the coordinates of the distorted image.

Results: Figure 1 shows the brain images of a healthy volunteer for a simulation of an acceleration factor of 6 in the PSF encoding. Fig 1a shows the distorted EPI image, and Fig 1b shows the corrected EPI image. For comparison in Fig. 1c the corrected EPI image using the fully sampled dataset is represented. Fig 1d displays the distortion free gradient echo image. Reduced folding artefacts in the PE encoding remain visible. Fig. 1e illustrates the PSF data in read - Y_{EPI} coordinates for Y_{GE}=19. In the absence of distortions this line would be horizontal. Fig. 1f shows the PSF data in Y_{EPI}-Y_{GE} coordinates for X = 33. In absence of distortions this line would be aligned to the diagonal. The folding artefacts are effectively suppressed.

Discussions/Conclusion: This study demonstrates that the compressed sensing technique can be used to efficiently reconstruct the PSF data set with high acceleration factors. With the presented method, the geometric distortions of echo-planar imaging were accurately estimated. The PSF technique is very robust and does not require 2D phase unwrapping methods that are generally used for dual echo field mapping approaches.

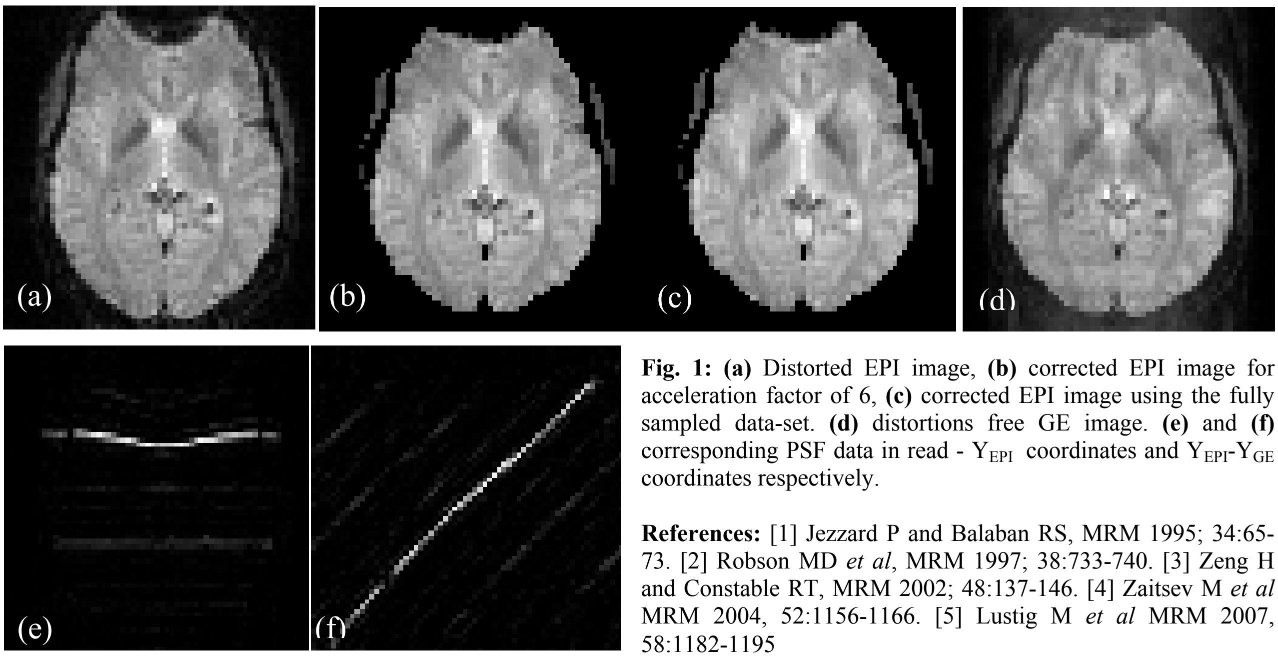

Fig. 1: **(a)** Distorted EPI image, **(b)** corrected EPI image for acceleration factor of 6, **(c)** corrected EPI image using the fully sampled data-set. **(d)** distortions free GE image. **(e)** and **(f)** corresponding PSF data in read - Y_{EPI} coordinates and Y_{EPI}-Y_{GE} coordinates respectively.

References: [1] Jezzard P and Balaban RS, MRM 1995; 34:65-73. [2] Robson MD *et al*, MRM 1997; 38:733-740. [3] Zeng H and Constable RT, MRM 2002; 48:137-146. [4] Zaitsev M *et al* MRM 2004, 52:1156-1166. [5] Lustig M *et al* MRM 2007, 58:1182-1195

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