Review of Current Methods for Geometric Deformation Correction in EPI

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Background

EPI artifacts : geometric distortion, signal drop-out, Nyquist ghosts
Causes : B0 field inhomogeneity, gradient eddy currents, radio-frequency pulse frequency offset, and chemical shift effect
Ex) magnetic field inhomogeneity in the paranasal sinuses :
1 ppm (125 Hz at 3T) ≈ 4 pixels for a 64 x 64 matrix with a 125 kHz bandwidth

A. Field map methods : offset spin echo, double gradient-echo images
distorted field map, undistorted field map
undoing phase error, pixel shift
- ✓ Conjugate phase reconstruction method
- ✓ Weisskoff method
- ✓ Conjugate-gradient methods (*Munger*)

● difficult phase mapping for areas of near edge, high-field inhomogeneity
phase unwrapping problem
lack of information on voxel intensity
unable to correct eddy current effects

B. Point spread function method (*Zeng*)
- ■ can correct both intensity and geometric distortions
- ● only provide geometric distortion information in phase-encode directions

C. Reference scan methods :
- ✓ Multiecho reference scan (*Schmithorst*)
- ✓ Multireference scan (*Wan*, *Chen* and *Wyrwicz*)

■ avoid phase unwrapping problem, possibly encodes dynamic factor
● longer scan time

D. Image based approach :
- ✓ Two magnitude images with orthogonal phase encoding directions
- ✓ Two acquisition having different polarity of phase-encode blips

Paper Review

1. Jezzard P., Balaban R.S. Correction for geometric distortion in echo planar images from B0 field variations. *Magn Reson.Med* 1995; **34**: 65-73.

Method :

Field map using double gradient echo images
Spatial smoothing
2D polynomial surface fitting
Image unwarping along the phase encoding direction : linear interpolation
Intensity correction : adding local pixel shift gradient

Discussion :

de facto standard

2. Reber P.J., Wong E.C., Buxton R.B., Frank L.R. Correction of off resonance-related distortion in echo-planar imaging using EPI-based field maps. *Magn Reson.Med* 1998; **39**: 328-330.

Method :

EPI-based field maps, gradient recalled images collected across a range of TEs
Field map to be unwarped, providing a direct look-up table for the correct location of each pixel of data.

Discussion :

Adds very little scan time, robust and easy to implement

3. Munger P., Crelier G.R., Peters T.M., Pike G.B. An inverse problem approach to the correction of distortion in EPI images. *IEEE Trans.Med Imaging* 2000; **19**: 681-689.

Method :

Conjugate gradient algorithm by solving the EPI imaging equation

Discussion :

Outperform the conjugate-phase approach

4. Kadah Y.M., Hu X. Simulated phase evolution rewinding (SPHERE): a technique for reducing B0 inhomogeneity effects in MR images. *Magn Reson.Med* 1997; **38**: 615-627.

Method :

Distortion kernel calculated using an initial estimate of the image and a corresponding field map, rewinds the accumulated phase in the k-space data, subsequent Fourier transform to produce the final image

Discussion :

General approach applicable to a variety of sequences (single-shot echo-planar imaging, segmented echo- planar imaging with centric reordering, and spiral sequences)

5. Kadah Y.M., Hu X. Algebraic reconstruction for magnetic resonance imaging under B0 inhomogeneity. *IEEE Trans.Med Imaging* 1998; **17**: 362-370.

Method :

Formulated an inverse problem of a linear Fredholm equation of the first kind using field mapping and the k- space trajectory of the imaging sequence Employed singular value decomposition and conjugate gradient method

6. Schomberg H. Off-resonance correction of MR images. *IEEE Trans.Med Imaging* 1999; **18**: 481-495.

Focus :

Rigorous analysis of the family of conjugate-phase methods with an assumption of the existence of a “time map”

Discussion :

Preferable to SPHERE method, at least for spiral image

7. Wan X., Gullberg G.T., Parker D.L., Zeng G.L. Reduction of geometric and intensity distortions in echo-planar imaging using a multireference scan. *Magn Reson.Med* 1997; **37**: 932-942.

Method :

Phase-encoded multireference scan
EPI data is corrected using both the amplitude and phase of the measured errors.

Discussion :

Effectively reduce the geometric and intensity distortions

8. Chen N.K., Wyrwicz A.M. Optimized distortion correction technique for echo planar imaging. *Magn Reson.Med* 2001; **45**: 525-528.

Method :

Multichannel modulation postprocessing algorithm (Chen and Wyrwicz, MRM 1999;41:1206- 1213)

Discussion :

Effective in removing distortions due to gradient waveform imperfections and phase gradient-induced eddy current effects

Simultaneous correction of different off-resonance factors without use of a complicated phase unwrapping procedure

9. Schmithorst V.J., Dardzinski B.J., Holland S.K. Simultaneous correction of ghost and geometric distortion artifacts in EPI using a multiecho reference scan. *IEEE Trans.Med Imaging* 2001; **20**: 535-539.

Method :

Multiecho, gradient-echo reference scan (takes additional 2 mins)
utilizes phase information in two dimensions

Discussion :

Computationally efficient technique for the simultaneous removal of ghosting and geometrical distortion artifacts

10. Zeng H., Constable R.T. Image distortion correction in EPI: Comparison of field mapping with point spread function mapping. *Magn Reson.Med* 2002; **48**: 137-146.

Method :

PSF approach : acquisitions with additional phase-encoding gradients to encode the distortion and the distribution of intensities
Deconvolution of distorted image with the PSF

Discussion :

Allows the distortion in geometry and intensity to be corrected

11. Langlois S., Desvignes M., Constans J.M., Revenu M. MRI geometric distortion: a simple approach to correcting the effects of non-linear gradient fields. *J.Magn Reson.Imaging* 1999; **9**: 821-831.

Method :

A model of non-linearities, derived from the geometry of the gradient coils

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