Performance Assessment of EPI-Distortion Correction of Brain Images; Which Plane and Phase Encoding Direction Should be Chosen?

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1. Introduction

- Echo-Planar-Imaging (EPI) is often used in DW-MRI to acquire a full volume in a short period of time.
- These images show substantial local geometric and intensity distortions due to the susceptibility artefact; A conventional 2D EPI imaging sequence would provide us a set of descritize samplings of the Fourier transform of the image:

\[ S(k_x, k_y) \propto \varphi(x, y) e^{-2 \pi i \Delta B(x, y) / \gamma} \delta dx dy, \]

where \( \Delta B \) denotes the magnetic field homogeneity.

- A popular method to correct for these distortions is to acquire a pair of images with opposite phase-encoding-directions (PED) but same slice-encoding-direction (SED) from which the distortion field can be estimated. While the choice of SED and PED likely impacts the correction effectiveness, it has never been rigorously quantitatively evaluated.

2. Objective

Our aim was to compare the impact of both SED and PED on the EPI-corrected data. To do so, we acquired scans with all combinations of SEDs and PEDs and evaluated the correction quality of three different distortion correction implementations by comparing them with a distortion-free T2 scan.

3. Method

- In-vivo MR imaging was carried out on a 3T Siemens scanner with 64 channel coil. We acquired DWI scans of a healthy subject with all possible SED (axial, sagittal, coronal) and all PEDs for each, leading to 12 acquisitions: AX-LR, AX-RL, AX-AP, AX-PA, SAG-HF, SAG-FH, SAG-AP, SAG-PA, COR-LR, COR-RL, COR-HF, COR-FH. The parameters were: matrix size=128x128x90; resolution=2x2x2mm3; TE=89ms 5900msec; TR=8100ms, a single b=0s/mm2 image. A T2 image (matrix size=256x256x80; resolution=1x1x2mm3) was also acquired and used as a distortion free reference image.
- We investigated three different EPI-distortion correction methods: Topup [1], Tortoise [2], and a recent block-matching registration approach [3]. Images with opposite PEDs were fed to each algorithm. The T2 was also fed to tortoise.
- To assess the similarity between the corrected-B0s and T2 image:
  - We first rigidly registered them to the T2 image.
  - Then, we computed mutual information (MI) between the images of the voxels within the brain mask. Our hypothesis was that a higher similarity would be achieved in the presence of a better EPI-corrected image.
  - We also performed non-rigid registration using ANTS [4] between the corrected B0s and T2 image to evaluate the amplitude of the remaining distortion. Our hypothesis was that a more successful EPI-correction would lead to less remaining deformation.

4. Results

Examples of the rigidly registered B0 images for one set of the images with sagittal SED and head-foot (HF) foot-head (FH) PEDs are shown in Fig.2.

![Figure 2: Visualization of the B0s (before and after distortion correction) on top of the T2 image; checker-board representation and RGB representation on which the red and green channels encode B0 and T2 images, respectively. Different columns represent images for: a) B0 of forward (SAG-FH); b) B0 of backward (SAG-FH); corrected B0 by: c) block matching [2]; d) Tortoise [4]; e) Topup [3].](image)

Our quantitative evaluation is reported in Fig 3-4. It can be seen that MI is higher for coronal and sagittal SED compared to the scans with axial SED. Further, it can be noted that based on MI metric, Topup leads to the highest similarity.

![Figure 3: MI computed between the T2 image and B0s (B0 of the forward: base1; backward: base2; B0 of the EPI-corrected data computed by: Topup [3], Tortoise [2], block-matching [3]).](image)

![Figure 4: Visualization of the localized MI computed at patches of size 5x5x5 between the B0-corrected images and the T2 image; (a) Cor-LRRL and AX-LRRL; (b) AX-APPA and SAG-APPa; (c) SAG-FH and SAG-HF; (d) SAG-FH and COR-LRRL.](image)

We performed non-rigid registration over the B0 images. The means and histograms of the remaining deformations after correction are reported in Fig.4. It can be seen that without any correction (baseline images, red and orange plots) have more deformation compared to the corrected images, as expected. Moreover, the plot shows that Tortoise leads to the least remaining distortion. Comparing the results for different SEDs and PEDs, it can be seen that the quantitative results by Topup and block-matching are consistent for both metrics and the results indicate that sagittal and coronal SEDs lead to better accuracies/similarities/less-remaining deformation compared to the axial images. Our results indidate that PED does not matter for a given SED as long as FOV is large enough to avoid aliasing.

![Figure 5: Means of the deformations after applying non-rigid registration between the B0 images and the T2 image.](image)

5. Discussion and Conclusion

To the best of our knowledge, this is the first work to assess the impact of both SED and PED on the performance of EPI-distortion correction, which is an important issue to be considered in the settings of the DW-MRI protocols. On HCP dataset, the PED was chosen to be LR with axial plane in order to minimize the number of phase encodes and therefore the distortion. It was stated that axial-LRRL allows an approximately 20% reduction in echo time compared with axial-APPA, leading to an additional SNR benefit. However, there is not any direct comparison among EPI-corrections at different SEDs and PEDs [5]. Our quantitative results based on MI and remaining distortion suggest that COR-LRRL may provide better results. However, this also would result in a longer scan time since coronal acquisition requires a higher number of slices. Future work will focus on confirming these findings using a MR simulator of the the image formation that incorporates the simulation of susceptibility related distortions.

References

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