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 artifact; A conventional 2D imaging sequence would provide us a set of descritize samplings of the Fourier transform of the image:
  \[ S(k_x, k_y) \propto \int \rho(x, y) e^{-2\pi i (k_x x + k_y y)} \, dx \, dy, \]
  where \( \Delta B \) denotes the magnetic field homogeneity.

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 coils. We acquired diffusion-weighted images (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 59000ms<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-B0 images and T2 image:
  - We first rigidly registered them to the T2 image.
  - Then, we computed mutual information (MI) between the images for 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

Figure 2 shows examples of the rigidly registered B0 images for one set of the images with sagittal SED and head-foot (HF) foot-head (FH) PEDs. It can be seen that the corrected images resulted by applying the three evaluated methods [1,2,3] (the last three columns) are better aligned to the T2 image compared to the non-corrected images (the first two columns). However, it is hard to identify the best corrected image visually.

Our quantitative evaluation is reported in Figure 3. 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. The localize MIIs computed at patches of size 5x5x5 are shown in Figure 4, which are computed at patches of size 5x5x5 between the B0-corrected images and the T2 image at each SED/PED. (b) Pairwise differences between the localize MIIs for different SEDs/PEDs. The results indicate that the maximum MI correlation is achieved by COR-LRRL specifically at the sinus region. The results indicate that the maximum differences are achieved between COR-LRRL and the axial images specifically at the sinus region.

We performed non-rigid registration over the B0 images. The means and histograms of the remaining deformations after correction are reported in Figure 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 indicate that PED does not matter for a given SED as long as FOV is large enough to avoid aliasing.

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