Field Map Constrained Nonrigid Registration Method for Correction of Distortions in EP Images

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Introduction

Image post-processing techniques have been widely used in distortion correction for Echo Planar (EP) images. Two main strategies among them are field map [1-2] and nonrigid registration [3-5] methods. Field map methods employ a measured field map to calculate the geometric distortion in an EP image directly and then do correction using a pixel shift method [1]. The correction results are largely influenced by the accuracy of the field map measurements. Nonrigid registration methods, by aligning the distorted EP image to an undistorted (reference) image, employ a deformation field to approximate existing distortion. Physics based constraints have been added to help the registration process [3, 5]. The combination of these two methods has not yet been investigated. Here, we use a measured field map as a constraint for the registration process and we utilize nonrigid registration to compensate inaccuracies in field map measurements. The proposed methodology is demonstrated on simulated images and on a real EP image of a phantom.

Methods

The combination of field map and nonrigid registration methods is based on a physical model of EP imaging. Geometric distortion in EP images in the presence of an inhomogeneous B_0 field is mainly in the phase encoding direction (here y), and can be written as: $\Delta y = \gamma \Delta B \, \mathrm{FOV}_y / \mathrm{BW}_y$. Here, γ is the gyromagnetic ratio, ΔB is the perturbation of the B_0 field, FOV_y and BW_y are the Field of View and bandwidth in the phase encoding direction, respectively. Intensity distortion arising from this geometric distortion is described by a Jacobian factor $J^{-1} = (\partial y_1 / \partial y)^{-1}$ in which y_1 is where the original position y has been displaced. Additionally, for Gradient Echo (GE) EP images, signal attenuation due to through-slice (here z) intra-voxel dephasing is given by $h = \left|\mathrm{sinc}\left(\pi\gamma(\partial \Delta B/\partial z) v_z TE\right)\right|$, with v_z the voxel size of the EP image in the z direction and TE the echo time.

We first compute Δy directly from the field map and use it as the initial value for the deformation field of our nonrigid registration algorithm. At each step of the algorithm, Δy is used to compute J and h (for GE images), and the image intensity is multiplied by J/h . The algorithm uses a linear combination of radial basis functions (RBFs) with finite support to model the deformation field. Those RBFs are placed on a set of control points in the image and their amplitudes are changed to maximize the normalized mutual information between reference image and corrected image [5]. To accelerate the registration process and reduce the chances of falling into local minimum, we utilize information contained in the field map to constrain the optimization. Our strategy is based on one assumption: inaccuracies in field map measurements occur mainly where the field inhomogeneity is large or changes rapidly. We build a mask based on the magnitude and the gradients (in the y and z directions) of the measured field map. We place RBFs only inside this mask. We also consider the fact that intensity and dephasing corrections may not work well over areas with severe signal attenuation because of low SNR. This is addressed by identifying regions in the EP images below an intensity threshold and avoiding placing basis functions over these areas.

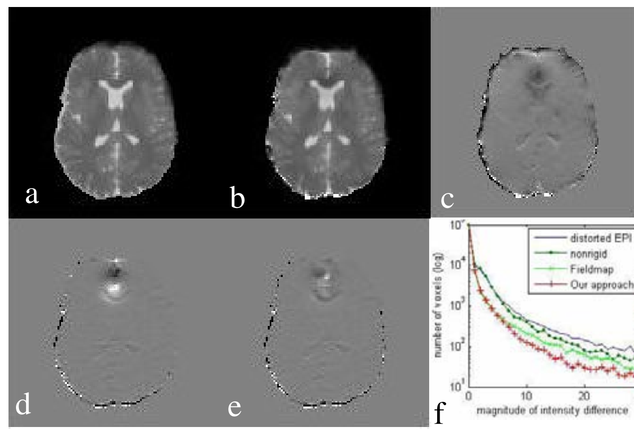

Fig. 1 a. distortion free EP image; b. distorted image; c. difference between a and b; d, e: differences between distortion-free EP image and corrected images with field map method (d) and our approach (e); f: histogram of difference images.

Results

Fig. 1 shows a simulated distortion-free image and its distorted version created with a real field map measured for a human brain. The field map is then perturbed to simulate measurement inaccuracy. This corrupted field map is subsequently used as the input to the field map method and our approach. Histograms of intensity differences between the distortion free image and the distorted image as well as the images corrected with (1) the nonrigid registration method only, (2) the field map method, and (3) the method we propose are compared in Fig. 1f. A lower curve indicates better results, and our proposed approach is clearly an improvement. Furthermore, our approach greatly speeds up the calculations because optimization is performed on only a small part of the image. In this case, CPU time was reduced to 0.80min from 4.3min.

In Fig. 2, an imaging phantom is used to compare results obtained with our approach to those obtained with the SPM FieldMap toolbox [6], which implements the field map method. Note that the shift near the right edge of the gray part to which the arrows point in 2c (SPM toolbox) has been further reduced in 2d (our method).

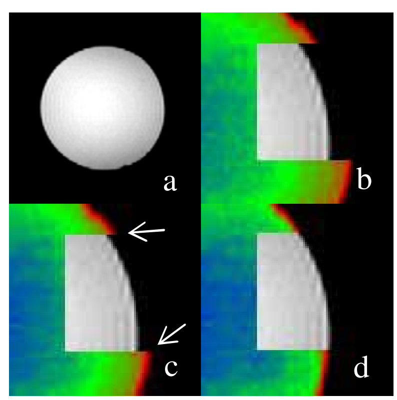

Fig. 2 a: reference image; b: overlay reference image to distorted image; c, d: overlay the reference image to corrected images by SPM FieldMap toolbox (c) and our approach (d). (b, c and d are magnified to show the differences)

Conclusions

We propose a strategy for the correction of distortions in EP images, which combines field map and nonrigid registration methods. Using the field map both to initialize and to constrain our non-rigid registration algorithm, we can improve on results obtained with either method alone. Ongoing work includes evaluating this approach on real brain EP images.

References

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