Combining EPI and motion correction for fMRI human brain images with big motion

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Abstract— **Motion correction is an important component in fMRI brain image analysis. Linear registration technique is mostly used in the process based on the assumption that there is not any shape changes of human brain during imaging process. Echo planar imaging (EPI) technique has been widely adapted in fMRI imaging to shorten encoding duration and increase temporal resolution. However, due to the magnetic field inhomogeneity caused by tissues, shape distortion and signal intensity lose are brought into fMRI images by the technique. On the other hand, subject's pose in scanner has a effect on magnetic field inhomogeneity, so the EPI distortions are subject to head movement, especially when the movement is big. As a result, most current motion correction techniques, which are based on rigid registration, cannot handle the problem. In this paper, a technique that combines EPI distortion correction and motion correction to handle the above-mentioned problem is proposed. Since it is almost impossible to obtain ground truth at present, a task-related fMRI BOLD time course image with big motion is selected as experimental material to test its performance. The image is pre-processed with the proposed EPI-motion correction scheme then analyzed by FSL feat tool [1]. Compared with another process with only motion correction and FSL feat analysis, the experimental result using the proposed method has no false activation detection. It is suggested the proposed EPI-motion correction scheme has the ability to handle the fMRI human brain images with big motion.**

I. INTRODUCTION

Due to uncomfortable environment, curiosity, pain, task, disability and other reasons, movement of subject (patient) is mostly inevitable during fMRI temporal sequence imaging process. Thus motion correction is an important component in fMRI brain image analysis [2], [3]. However, there are still a large portion of fMRI images have to be discarded due to failed motion correction. The causes of the failure are complicated. The most common reason is intra-volume movement between slices [4]. Because most current motion correction techniques treat the problem as a rigid registration process, and intra-volume movement cause non-linear distortions within the volume, the images with too many intra-volume movement have to be dropped. If the number of volumes in a sequence that suffer from intra-volume movement is not high, it is possible to drop the affect volumes and make use of the remaining volumes for analysis. However, current techniques still may fail to correct the motion distortions if the remaining volumes are in different pose, which is due to the non-linear distortions caused by Echo Planar Imaging (EPI) technique.

Recently, Echo Planar Imaging (EPI) technique has been widely introduced into fMRI image acquisition process to shorten encoding duration and increase the temporal resolution. Due to the inhomogeneous magnetic field cause by human tissues, there exist shape and intensity distortions (and even signal loss) in the acquired images [5], [6]. The distortions are subject to the shape and pose of subject's head so it causes an inaccurate motion correction result especially when motion (especially rotation) is big [7]. V. Roopchansingh *et al* [8] suggested to insert field map acquisitions into the EPI time courses, then use the field maps to correct the distortions as the head is moved. However, care must be taken to avoid introducing additional noise to the EPI time course by using noisy field map information [9]. Moreover, the insert of field map acquisition would decrease temporal resolution of acquired image. In [10], Boegle *et al* captured field maps on various orientations on a phantom beforehand, and used the field maps to correct EPI time course for subjects. However, the method may bring more noise if the difference between the phantom and subjects' head is big.

Recently, active marker based motion correction techniques have been developed to handle the problem [11], [7]. The type of techniques make use of active markers to track the movement of subjects during acquisition process and use the information to correct acquired images slice by slice. Obviously, these are the most promising techniques to handle the motion problems although they still have some limitations. However, these techniques have not been introduced into clinical practice. Considering the huge amount of fMRI data with big motion that acquired recently or in near future without the technique, it still worth our efforts to develop new retrospective tools to correct the distortions.

In this paper, we developed a new scheme that combines EPI and retrospective motion correction to handle the fMRI images with big motion, in the cases that intra-volume movement is limited. The paper is organized as following: Section II gives a detailed introduction of the proposed scheme. The details of experimental materials and processing methods are presented in section II. The experimental results and discussions are given in section IV.

II. THE PROPOSED EPI-MOTION CORRECTION SCHEME

Flowchart of the proposed scheme is shown in Fig. 1. A number of FSL (FMRIB Software Library) [1] and ANTs

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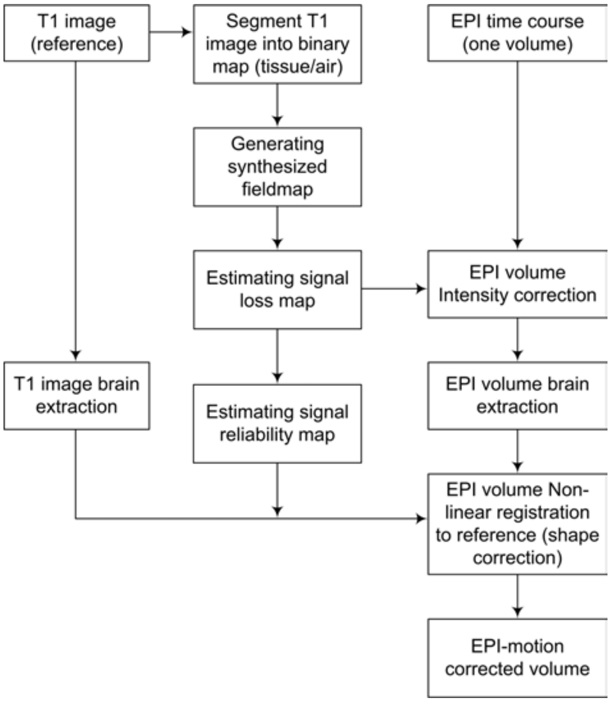

Fig. 1. Flowchart of the proposed scheme.

(Advanced Normalization Tools) tools have been used in the processing. FSL a software library containing image analysis and statistical tools for functional, structural and diffusion MRI brain imaging data; and ANTs [15] is a medical image registration and segmentation toolkit.

The inputs are an fMRI brain image (or generalized as a EPI time course) and a structural T1 image of the subject. The T1 image is used the reference of the EPI-motion correction. The first step in the scheme is to separate the T1 image into air and tissue two classes by FSL FAST tool [12]. Then FSL b0calc and other tools [13], [1] have been used to generate the synthesized field map (phase) image for each volume of the input EPI time course. Based on the synthesized field map and deprived signal loss map, the intensity of the volume has been corrected, and the brain image is extracted from the intensity-corrected volume by FSL BET 2.0 tool [14]. Afterwards, a reliability map of the volume is generated from the signal loss map, and used as a weighting mask in the non-linear registration to correct shape distortion. As noted that instead of using FSL non-linear registration tool (fnirt) in fugue, ANTS non-linear registration tool has been adapted in the step. The reasons are:

1) The inaccuracy of air-tissue segmentation in T1 image causes artifacts in the reconstructed field map;
2) EPI distortions are subject to scanners and the factors such as shimming; and
3) The influence of tissues outside of FOV.

Besides the intensity- and shape-corrected EPI image, the reliability map of each volume are also cast into T1 space and merged into a single 3D image as a reference of output. The final reliability map can be used as an index of reliability in fMRI image analysis.

III. MATERIALS AND METHODS

One fMRI BOLD time course image (EPI image), which is selected from a stroke patient MRI data set, has been used in the study together with a correspondent T1 structural image. The subject was in the second half of 50s at the time when the image was acquired. He had his subcortical stroke in right side of brain hemisphere for more than 1 year time time before leading to a severe impairment in the upper limb. His Fugl-Meyer Assessment (FMA) [16] score of the affected hand estimated one week before the scanning is 28. The subject was recruited with written consent. MRI data was collected using a 3T scanner (Siemens Trio, Germany). In the scanner, the subject performed a active dynamic stroke-affected hand grip task cued by a visual stimulus of a moving red circle. fMRI BOLD data was acquired with a single-shot gradient echo EPI sequence with TR=3000 ms, TE=30 ms, voxel size=3.4mm isotropic, and number of measurements is 89 with a flip angle of 90 degrees. The T1 structural image was acquired using the same scanner with TR=1900 ms, TE=2.52 ms, and voxel size=1mm isotropic with a flip angle of 9 degrees and shimming enabled.

The rotation disparities between neighboring volumes of the EPI image are shown in Fig. 2, together with the task paradigm. As EPI distortion is basically subjective to rotation, only rotation disparities are shown here, and the unit of vertical axis in Fig. 2 is degree. It can be observed that the maximal rotation disparity in the image is more than 3 degrees. It can be assumed the big motion is mostly due to the dis-comfortableness in the scanner environment. The active task also contribute a lot to the head motion as the patient was trying hard to grip due to the disability caused by stroke. Moreover, his head moved in resting as well state due to the uncomfortable environment of the scanner.

Based on the relative motion disparities, a number of volumes, which have more than 1 degree rotation disparity in either x, y or z axis, had been removed. It is assumed that these volumes may suffer from intra-volume motion. Then after slice timer correction, the modified EPI image had been applied with the proposed EPI-motion correction scheme. As ground truth of the image is not available, we put the EPI-motion corrected image into FSL feat to detect the task-related activation regions. In FSL feat, the non-linear registration from T1 structural brain image to MNI152 template is replaced by ANTs [15]. To ensure the accuracy of the non-linear registration, the stroke lesion area has been manually labeled and masked out in the process. Since the input EPI image had already been pre-processed, only a 8mm smoothing is enabled in FSL feat pre-processing. The method is named as *EPI-motion correction + FSL feat* method.

The structural T1 image of the patient is shown in Fig. 3(a). The stroke lesion can be observed on his right half of brain hemisphere, and it falls in Corticospinal tract. The reconstructed field map (phase) image is shown in Fig. 3(b). It can be observed that the major affects areas,

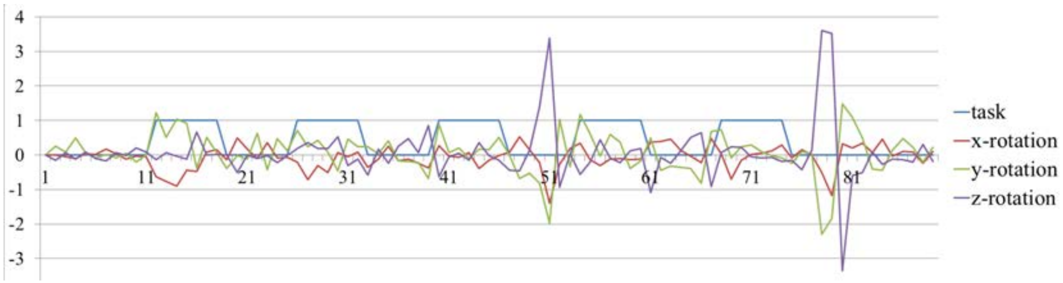

Fig. 2. The task paradigm and the motion (rotation) disparities.

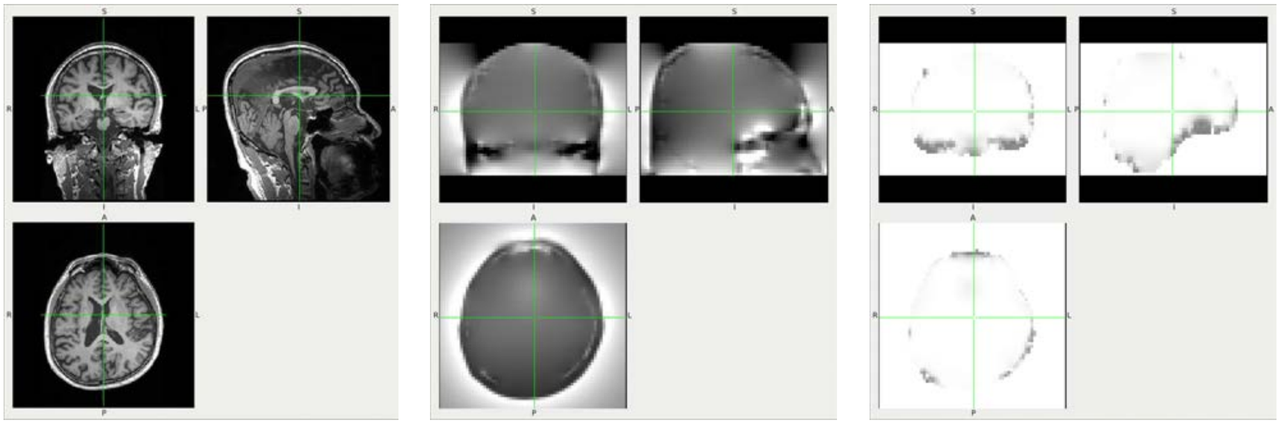
(a) (b) (c)

Fig. 3. (a) The structural T1 image of the patient; (b) the reconstructed field map (phase) image; and (c) the reliability map on EPI space for non-linear registration (shape correction).

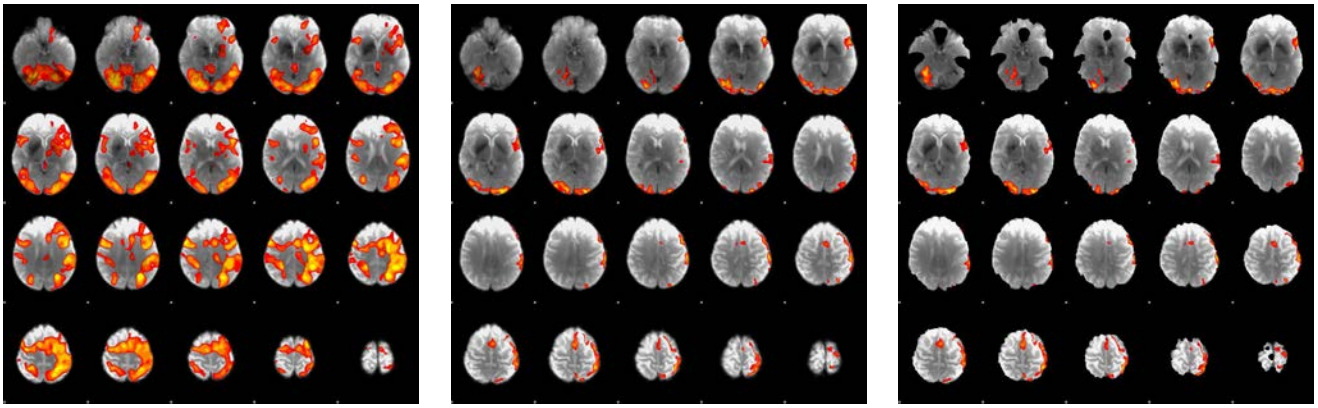
(a) (b) (c)

Fig. 4. The comparison of the selected fMRI BOLD time course image with big motion on different processing methods: (a) The activation regions detected using *FSL feat + ANTs*; (b) the activation regions detected using the proposed *EPI-motion correction + FSL feat* method; final reliability map; and (c) the reliable activation regions in (b) that masked by the reliability on EPI distortion.

such as frontal, extreme superior and inferior portions, are in line with our knowledge and the previous findings [5], [6]. However, as mentioned in section III, the reconstructed field map (phase) image may be have small differences to the real field map, and it should not be applied to correct the EPI distortions directly as in FSL fugue tool. Instead, by making using of the signal loss map generated by FSL fugue tool, we deprived a reliability map, as shown in Fig. 3(c), and introduce it as a weight image into the non-linear registration process by ANTs. The dark regions, which are suffered by EPI distortions, have low weight in the non-linear registration from EPI to T1 space.

In order to compare the performance of the proposed EPI-motion correction scheme, the modified EPI image, with slice timer correction but without EPI and motion correction, has been applied to FSL feat analysis. In the pre-process, motion correction and 8mm smoothing is enabled. To remove the bias in registration, the registration from example_func to T1 structural image had been replaced by ANTs registration [15]. The parameter settings that used in the proposed scheme has been applied in the process as well. The above-mentioned ANTs based non-linear registration from T1 structural brain image to MNI152 template is also used here. The method is named as *FSL feat + ANTs* method.

To generate the task EV for both methods, the task paradigm is firstly smoothed by standard gamma smoothing in FSL feat. Then smoothed paradigm is modified by removing the correspondent component to the removed volume in the input EPI image. Finally, modified paradigm in put into both FSL feat as task EV. Similarly, the 6-degree motion parameters, which were obtained by motion analysis, have been modified and add as additional confound EV. This is to further reduce the impact of subject motion. In both FSL feat post-processing, the detection results have been corrected by clustering and the p value is set to 0.005 in statistic analysis.

IV. RESULTS AND DISCUSSIONS

The experimental results are shown in Fig. 4: Fig. 4(a) shows the task-related activation regions detected by *FSL feat + ANTs* method. It can be observed that the motor and premotor areas in both side of brain and supplementary motor area (SMA) have been activated. Because it is an active task, visual cortex has been activated as well. However, it also can be observed that part of activation regions in left side of brain (right side of the image) fall in white matter areas. It has a high chance that the region is a false detection. The false detection is probably caused by a false motion correction as the EPI distortions impaired rigid registration. Fig. 4(b) is the detection results by *EPI-motion correction + FSL feat*. It can be observed that the detected activation regions are much smaller to Fig. 4(a), and the activation can be found in left (health) side premotor, motor cortex, SMA, and visual cortex in both sides. However, the motor activation in right (stroke) side of brain is gone. Considering the patient was suffering a severe dysfunction of affected hand, the phenomenon is explainable. Moreover, the activation does not extend to white matter and ventricular areas. It suggests the proposed *EPI-motion correction + FSL feat* method reduced the distortions caused by EPI acquisition technique and the movement of subject.

Considering the signal in EPI-affected regions have low reliability, we masked out the regions and Fig. 4(c) is the final analysis results. It can be observed that parts of premotor and motor areas are taken out as they are affected by EPI distortions.

Since there is no ground truth of brain activation in the selected image, it is impossible give an objective measure the how accurate of proposed EPI-motion correction scheme. However, by comparing the activation detection results by FSL feat with motion correction only, it suggests that using the image processed by the proposed scheme may have a low chance generating false detection. Indirectly, it confirms the performance of the proposed EPI-motion correction scheme on the analysis of fMRI human brain images with big motion. However, it worth pointing out the proposed scheme, as an image based approach, can effectively handle mostly the inter-volume motion. The scheme would fail if there is too much intra-volume motion.

ACKNOWLEDGMENT

This work was supported by the Science and Engineering Research Council of A*STAR (Agency for Science, Technology and Research). We would also thank Dr. Louis Shue who provided very helpful discussions and suggestions in the work.

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