Application of the Pseudo-Polar Fourier Transform for In-Plane Rotation Correction of MR Images

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INTRODUCTION:

A significant problem in MRI of the brain is the patient motion. It results in the reduction of the image quality and diagnostic information. The motion can be due to rotation or translation of the head. Sequences that acquire data from the centre to the periphery of the *k*-space in multiple-shot acquisitions, such as projection reconstruction, spiral and PROPELLER, reduce rotation artefacts by utilizing the oversampled non-Cartesian central *k*-space region. The central non-Cartesian region of *k*-space is contained in each shot and can be used to obtain a low-resolution image [1,2]. The low-resolution images, inherent in the Cartesian *k*-space based trajectories, are termed 2D navigator images. Registering the low-resolution images from each acquisition allows estimation of the in-plane rotation between the images. Generally, correlation techniques in the Fourier domain are used to solve the problem of calculating the rotation between the selected reference navigator image and the rest of the navigator images. In Fourier transform dependent schemes, the rotations and scalings are reduced to translations on the polar grid and can be recovered by correlation. Mathematically, polar grid computation uses the FFT algorithm whereas interpolation in the polar FFT computation is inaccurate. On the other hand, the Fourier transform dependent methods are iterative as they compute correlation between images for every possible rotation angle. To circumvent these problems, a method has been proposed in [3] which does not require a uniform polar representation and uses the algebraically accurate Fourier transform computed on the pseudo-polar grid. In addition, this method is non-iterative. Previously, this method has not been applied to the MR images acquired at high magnetic fields; this scheme is used in the present paper. It is elegant because the low-resolution imaging data themselves act as 2D navigators and the pseudo-polar Fourier transform is used to compute the rotation angles between the low-resolution images. This method was applied to images acquired using the EPI sequence on a 3T Trio system (Siemens Medical Systems, Erlangen, Germany).

METHODS:

In vivo images of a single healthy volunteer were obtained using the EPI sequence with the following sequence parameters: TR=3000 ms, TE=54 ms, BW=2170 Hz/Px, slice thickness=5 mm, FOV=237 mm x 237 mm, measurements=15 and matrix size=128 x 128. The patient rotated his head was during the multiple acquisitions. At the post-processing stage, the corresponding *k*-spaces of the images were obtained by applying the inverse Fourier transform to the images. For the selected slice, the low-resolution images were obtained by using only the central 48 phase-encode lines of the *k*-spaces. Due to in-plane rotation, the low-resolution images also rotated acquisition-to-acquisition. The pseudo-polar Fourier transform of each of the low-resolution images was obtained by using the Matlab toolbox provided in [4]. The computation of the pseudo-polar Fourier Transform is based on the Chirp Z-transform and the method is described in detail in [3,4]. One low-resolution image was selected as a reference and the others were aligned to it. The angular resolution was 128 and the resolution of a single ray in the pseudo-polar coordinates was 256. The relative rotation of the two images induces a cross pattern on the pseudo-polar Fourier transform of the difference of the two images. This cross pattern is robustly and accurately detected using the angular difference function proposed in [1]. The angular difference function was implemented. The rotation angle corresponds to the minimum of the angular difference function. The images were rotated by the calculated angles using nearest neighbour interpolation method. All methods were implemented using Matlab.

RESULTS:

The images of two different slices acquired in multiple simultaneous measurements are shown in Fig. 1 and Fig. 2. The rotated images are shown in the upper row of the figures. The corresponding rotation corrected images are shown in the bottom row. The images were aligned to the reference image which was selected from the initial measurement as there was no motion during the initial acquisitions.

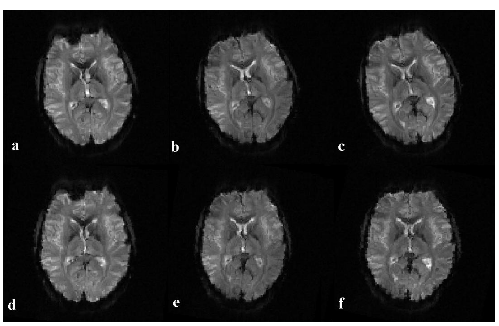

Fig.1.

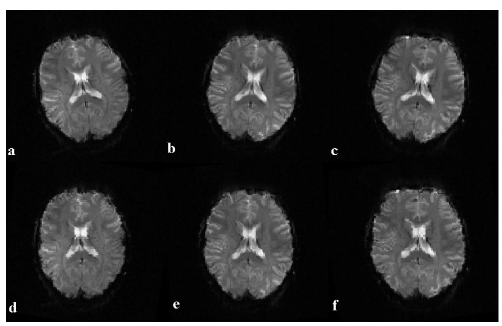

Fig.2.

Fig.1. a-c. The rotated images of a representative slice are shown. They were obtained during the multiple acquisitions using the EPI sequence. **d-f.** The corrected images are shown after applying the scheme described in this paper.

Fig.2. a-c. The rotated images of another representative slice are shown. They were obtained during the multiple acquisitions using the EPI sequence. **d-f.** The corrected images are shown after applying the scheme described in this paper.

CONCLUSIONS AND OUTLOOK:

Application of the psudo-polar Fourier transform and the angular difference function for rotation correction in MRI is a useful approach. This scheme is well designed because it is based on the Cartesian data set used for reconstructing the low-resolution images. This enables facile correction as compared to the radial or spiral data sets that are sensitive to higher phase differences and off-resonance effects. The applied method is without any interpolation errors and the computational complexity of the method is equal to the simple Fourier transform's complexity ($O(n^2 \log n)$). MR sequences that traverse a Cartesian trajectory in multiple shots are suited for such a scheme because each low-resolution image from a single shot can be used as a quick snapshot that inhibits the motion. Functional MR imaging (fMRI) is another application where rotation detection is crucial. In fMRI, EPI multi-slice data sets of the head are acquired during presentation of various stimuli. The acquired data sets must be aligned before performing any statistical test. In the EPI acquisitions, severe movement of the head between the different measurements of the same sequence can disturb the slice positioning and therefore the images to be registered are not the rotated replicas of each other. Consequently, the images might have different intensities and might have some uncommon parts. In such a situation the angular difference function does not compute the correct rotation angles. This function has to be extended to mitigate for such effects; this is currently being investigated.

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