Motion detection for diffusion weighted MRI using EPI phase correction lines

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Introduction: In order to represent complex white matter architecture, diffusion weighted MRI acquisition schemes with many directions is required. The increased number of diffusion directions required with these methods lengthens the total scan time. The sensitivity of diffusion imaging to motion combined with this increased scan time creates a need for a motion correction strategy, especially with uncooperative patients such as children. Kober et al. [1] suggested using free induction decay (FID) navigators to detect motion and initiate reacquisition of the volume corrupted by motion (and a B0 image to register) if the motion is higher than a certain predetermined threshold. Here in this work we investigated whether the presence of motion can be detected from the EPI phase correction lines that are acquired with each 2D slice. Like the FIDs these lines are acquired before the application of diffusion gradients, so they are not affected by different diffusion gradient strengths. Unlike for FIDs, there is no need to increase the echo time (avoids loss in SNR) and no modifications to the EPI sequence are required.

Methods: Experiments were performed with a 32-channel head coil on a 3T Siemens TRIO scanner. In order to directly measure motion, an electromagnetic motion tracking hardware system from Robin Medical [2] was used, together with a 2D SE EPI sequence modified with a gradient trigger for the motion tracker, providing an echo time of 79ms and TR of 9.6 seconds giving a total scan time of 5 minutes. FOV was 200cm and 70 slices were acquired with a slice thickness of 2mm. 3 adult volunteers were scanned using 30 directions with a b value of 1000. Raw data from the scanner was collected for each coil and a threshold was set according to the following metric calculated from the phase encoding lines:

$$metric(s) = median^{coils}(\left| \frac{line_n(s,c) - line_{n-1}(s,c)}{line_{n-1}(s,c)} \right|_2)$$, where s is the slice number, c is the coil number and n is the volume number.

Motion detection and reacquisition strategy: Each volunteer was scanned in two separate scans, where they directed to first stay as still as possible, and then to move at arbitrary time points during the second scan. Volumes with a reported motion higher than a threshold by the metric were reacquired.

Results: In Figure 1, the top plot shows the percent change in the transformation matrix reported by the motion sensor whereas the bottom plot shows the predicted motion calculated by the proposed metric. An FA map without motion is shown in Figure 2 (left). In Figure 2 (middle) the FA map calculated from the same patient with the motion pattern in Figure 1 is shown. Figure 2 (right) shows the same data with the suggested reacquisition scheme.

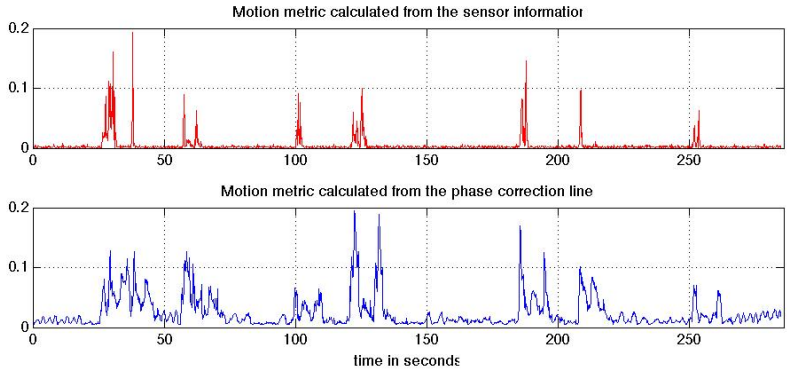

Figure 1 (top), motion reported by the electromagnetic tracker (bottom), motion metric calculated from the phase correction lines.

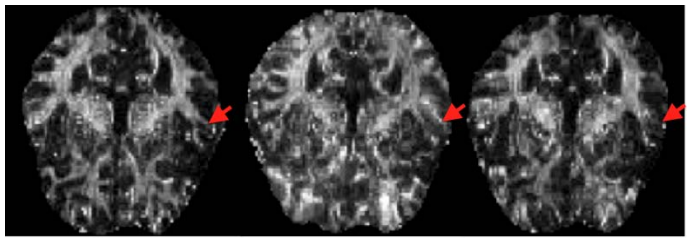

Figure 2 (left) shows FA map calculated from a study where no motion above the threshold was detected, Figure 2 (middle) shows a study where the patient moved during the scan, Figure 2 (right) shows the output of the reacquisition strategy applied to that dataset.

Discussion: As can be seen in Figure 1, the motion was successfully detected by the defined metric (with a correlation of 0.97 between two metrics thresholded to indicate presence of motion in a volume). It should be noted that with the suggested method each phase encoding line is compared with the previously acquired phase encoding line from the same slice. Therefore when motion occurs, the slices acquired after that point are also marked by the metric. On the other hand, the motion sensor data provides differences compared to the previous time point (one slice). Figure 2 (right) shows an improved FA map compared to the dataset where motion is not compensated. (PSNR increased from 21.01 to 27.43) Here the subject motion corrupted 7 different diffusion directions so the total scan time to reacquire the motion corrupted volumes is increased by slightly more than one minute.

Conclusion: We demonstrated that the information from the phase encoding correction lines acquired with an EPI acquisition can be used to detect motion in real time, and can be used to improve the quality of long diffusion scan when there is substantial motion during the scan.

References: 1. Kober, T., Gruetter, R., & Krueger, G. (2012).*NeuroImage*, *59*(1), 389-398.
2.. Gholipour, A., Polak, M., van der Kouwe, A., Nevo, E., & Warfield, S. K. *EMBC, 2011* (pp. 5722-5725).
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