

Real-time Motion Correction in 3D EPI using Cloverleaf Navigators

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Introduction and Background

Echo Planar Imaging (EPI) is the method of choice for functional MR Imaging (fMRI) studies and especially functional neuroimaging where rapid scanning is required to follow brain activations induced by various stimuli. While multi-slice EPI is commonly used to acquire 3D datasets, 3D EPI offers the advantages of creating thinner and contiguous slices, as well as generating a higher signal to noise ratio. 3D EPI however is more sensitive to subject motion since the determination of spatial location within the volume involves every acquired line of k-space. The evaluation in real-time of rigid body motion by means of navigators can help to overcome this disadvantage. We have developed a 3D EPI sequence with embedded cloverleaf navigators, which enables the detection and the correction of motion in all 6 degrees of freedom during the acquisition of each partition (3D slice) of each volume.

Compared to orbital [1] or spherical navigators [2], the original k-space trajectory of the cloverleaf navigators [3] [4] enables a rapid estimate of both translations and rotations involved in the motion of the subject. The phases measured on the straight-line segments of the navigator's trajectory are used to evaluate the translations. The rotation angles can be deduced from the comparison of the navigator with a pre-registered map of navigators acquired for various artificial rotations.

Methods

Figure 1 shows one block of the 3D EPI sequence with its phase encoding step along the slice selection axis and with the embedded cloverleaf navigators. The navigator block itself - included just after the EPI readout - occupies 9.1 ms of each TR (defined as the time to encode one partition) and has its own RF pulse, prephasing and refocusing gradients. The navigator could share the existing main RF pulse - it would then have to be included before the EPI readout resulting in an increased minimum TE (in BOLD imaging, TE is usually greater than minimum). The computation of motion parameters only takes 3 ms and is easily completed in a single TR. Online motion detection and correction in 3 dimensions has already been achieved for EPI by comparing each volume acquired with the previous one [5]. In

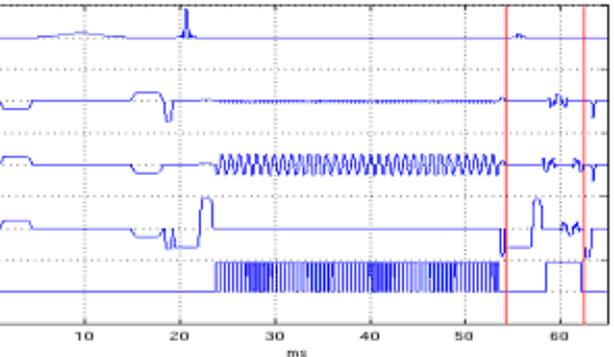


Figure 1- EPI with cloverleaf navigators pulse sequence block

our sequence however, the navigators are inserted every TR and detect the motion of the subject partition-by-partition instead of volume-by-volume. The rigid body estimate of the translations and rotations between two partitions is used to correct the acquisition parameters every TR. The gradients are adjusted according to this 6-dimensional motion in real time to reposition and reorient the next partition.

Results and Conclusion

Figure 2-a shows the translations and rotations of the head of a subject detected by the navigators during a 74 s scan. The rotations around the head-foot axis, first to the right side, then to the left, and back to a neutral position (shown in blue on the bottom-left graph) are successfully tracked by the navigators. Translations along the left-

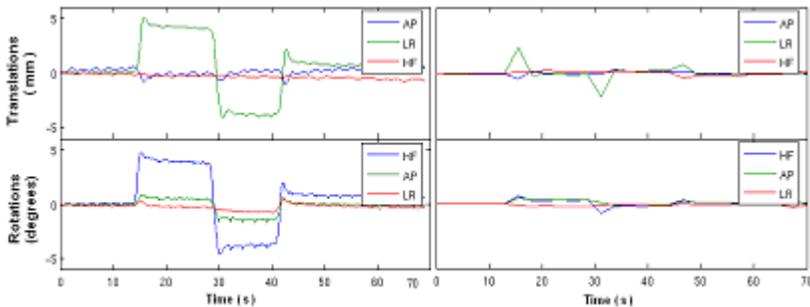


Figure 2-a: Motion of subject detected and corrected every 70 ms during a 74 s whole brain 3D EPI scan (30 measurements)

Figure 2-b: Remaining motion detected offline after online motion correction

right axis are also detected and are most likely due to the shift of the head's center of gravity during the rotation. Figure 2-b shows the remaining motion detected offline after online motion correction. As expected the navigators corrected for most of the subject's motion. Small left-right translation peaks are still detected during the transitions. Rapid motion during the navigator's measurement itself might indeed induce small errors in the motion estimation. Relatively rapid and large movements also have effects on image distortion in EPI, potentially impacting the offline motion detection.

The images of the brain obtained during this experiment are presented in Figure 3. The first two images on the top row were acquired with online motion correction, respectively 20 s (head rotated to the right) and 35 s (head rotated to the left) after the start of the scan. The third image results from the subtraction between these two images. The same procedure is employed for the bottom row, except that no online motion correction was used. These pictures clearly show the efficiency of the navigators to maintain the brain in the same position in the image, whilst the brain is shifted towards left and right in the absence of motion correction during the volume acquisition. Cloverleaf navigators therefore improve the image quality of 3D EPI scans, which is beneficial to applications involving the 3D EPI technique such as high-resolution functional imaging.

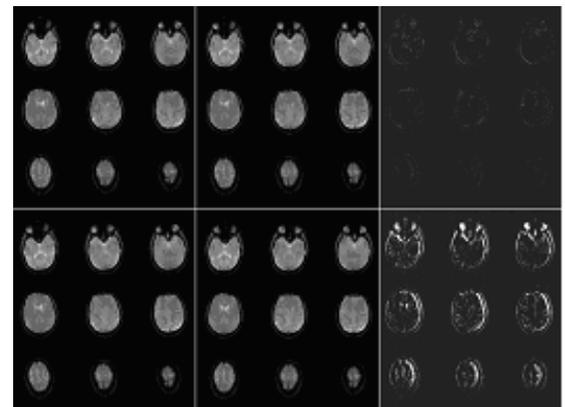


Figure 3 - Images acquired at $t_1=20$ s and $t_2=35$ s during a $TR=70$ ms scan and their subtraction, with online motion correction (top row) and without (bottom row)

Acknowledgments

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References

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