Motion mitigation for eye imaging using cloverleaf navigators

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Introduction and Background

High-resolution imaging of the human eye in-vivo is exacerbated by involuntary motion [1]. The eye performs small saccadic movements at irregular intervals, and moves during blinking. These movements are manifest in the MR image as blurring, and smearing in the phase encoding direction. We present a suggestion for dealing with this type of motion during imaging by oversampling in k-space while simultaneously collecting embedded motion-detecting navigators at every repetition time of the running scan. We reconstruct the image off-line by averaging only those lines of k-space that are not corrupted by motion.

Methods and Results

A sequence with embedded cloverleaf navigators [2] was used to image the eye on a 3 T Siemens Tim Trio. This 3D gradient echo sequence included a navigator after the readout at every TR of 21 ms. Imaging resolution was 0.5 x 0.5 x 1 mm (40 slices, 128 mm FOV). The cloverleaf navigator path in k-space includes straight-line sections in the three principal directions to assess translations of the object being scanned, and quarter-circles in each plane to assess rotations of the object about the three major axes. In this application we used only the mean square error between the signal collected along the quarter-circle sections in k-space of the navigator, and an average reference (obtained by selecting the median 50% of navigators acquired during the run). We collected four volumes, during which the subject performed deliberate blinks and small saccades at predefined times (differing in each scan), and also blinked involuntarily. Total acquisition time was 3:39 (min:s) per scan. We then corrected the volumes for eye blinks by smoothing k-space lines for which the MSE of the corresponding (closest) navigator was greater than 15% of the peak MSE throughout the run. Smoothing refers to replacing the erroneous k-space line with the average of its neighbors that are assumed to be more representative of the truth. The subject fixated with the left eye on a cross (except while performing 15 deg. deliberate saccades) while the right eye was imaged with a local surface coil of 3 cm diameter mounted just anterior to the eye. Raw k-space data were collected for post-processing.

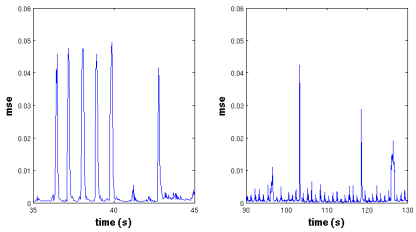

Figure 1: MSE of navigators collected during eyeball scan. (Left) MSE during 5 deliberate blinks followed by an involuntary blink, (right) MSE during a left saccade (small deviation), two deliberate blinks, and a right saccade (slightly larger deviation)

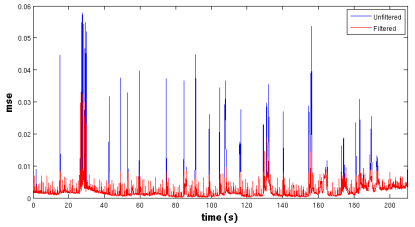

Figure 3: MSE plot for a complete scan shown before and after filtering.

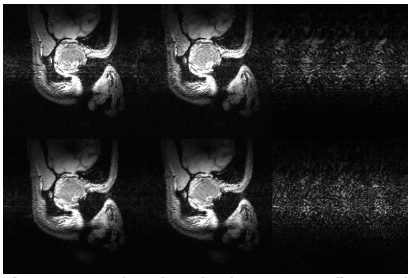

Figure 2: (Top) Single scan, (bottom) average; (left) before filtering, (middle) after filtering, (right) difference.

Figure 1 shows the MSE trace obtained using the navigator. Deliberate and involuntary eye blinks are clearly detected as shown on the left. Voluntary saccades are also detected as smaller deviations of greater duration as shown on the right of this figure. If the MSE data are used to correct the image, the remaining MSE can be estimated from the MSE values for the averaged neighboring lines of k-space. This is shown in Figure 3. Figure 2 shows the resulting images. The top row shows an image from a single scan without and with filtering based on the navigator motion detection, together with the difference in images (motion artifact). The bottom row of Figure 2 shows the improvement after averaging the four acquired volumes.

Conclusion

The navigator technique appears promising for detecting involuntary blinks and saccades. While our preliminary images appear to show an improvement with averaging and correction, we will quantify the performance in further work. Our current method does not include real-time correction for bulk motion of the head, although this should in principle be possible using the phase information from the straight-line sections of the navigator. We also do not include a mechanism to recover from extended periods of non-fixation that may occur if the subject loses concentration during the scan. This could be achieved with the same feed-back mechanism that is used to correct for motion in real-time by the standard navigator sequence. With or without image correction, our early navigator results suggest that a qualitative wireless eye tracking system may be possible using only the MR signal.

Acknowledgement

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References

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