

Parallel Imaging in Functional MRI: Comparison of Spiral SENSE and GRAPPA and of Calibration Update Schemes

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Introduction

Parallel imaging has been applied to many application areas of MRI to reduce scan time and improve image quality. It may also be useful for functional MRI, for which a large number time points are required, however, there are a number implementation details that need to be resolved. Several parallel imaging techniques involving temporal data such as TSENSE[1] and TGRAPPA[2] have been introduced. In these, estimating missing k-space lines uses data from other neighboring time points, however, little work has been done on approach to updating the calibration data, such as sensitivity map (SENSE) and GRAPPA weights (GRAPPA), for functional MRI. In this study, spiral SENSE and spiral GRAPPA are used and compared in terms of SNR in time course, image error when compared to fully sampled data, and number of activated pixels. Several update schemes for parallel imaging calibration data are also compared for cases of minimal head motion and large head motion.

Method & Experiment

In this study, a functional experiment was conducted in order to compare the performance between spiral SENSE and GRAPPA. Investigation of different update schemes for calibration data was also examined. A 3T GE scanner with a 8-channel array coil was used and the imaging parameters were TR=2 sec, TE= 25msec, flip angle=80°, FOV = 22cm, 64x64 matrix with 2-shot spiral trajectory. Five healthy volunteers (two male, three female; mean age 22±3 years) were participated in the functional study after informed consent. The task was a finger tapping task with reversing checkerboard visual pattern of (20 s ON)/(20 s OFF), repeated 4 times for a task period of 10 time points with 40 total time points. The acquired data were reconstructed using both spiral SENSE and GRAPPA methods. For reconstruction of spiral SENSE, iterative conjugate gradient (CG) method is [3] used. The sensitivity maps are derived by dividing a fully sampled coil image by the geometric mean of coil images [4]. The reconstruction algorithm was speeded up by using fast iterative algorithm [6]. For spiral GRAPPA, constant-linear velocity spiral trajectory data are resampled into constant-angular spiral trajectory so as to be considered as Cartesian GRAPPA technique [5] and conjugate phase approach was used to reconstruct the image. Magnetic field maps were used to correct of spiral blurring for both reconstruction methods. For each time point, the reference interleaves is alternated such as in TSENSE. The final reconstructed images were lowpass filtered in time (bandwidth that filters out the 10% of high frequencies) to suppress variations from alternating shots. In order to examine differences between SENSE and GRAPPA, reconstructed images are compared by SNR in time series, number of activated pixels, and errors relative to a fully sampled image. Three different scheme for updating the calibration data (the sensitivity map or GRAPPA coefficients) were considered: (1) using values acquired at 1st time point for all images, (2) updating the calibration data at every time point, and (3) updating at every time point using moving average of 5 neighboring time points. Moreover, in order to see the effect of motion, during additional separate scan, subjects were told to move their head according to the movement of checkerboard that was moving left to right and back to left at every 20 seconds during visual activation.

Results

SENSE vs GRAPPA The reconstructed image of visual cortex using one of two interleaves of k-space data is compared with fully sampled data for SENSE and GRAPPA in Figure 1. Figure 2 shows the performance comparison of GRAPPA(A,B) and SENSE(C,D) and the effect of temporal filtering(B,D) by number of activated pixel, error in image and SNR in time series for motor cortex (left) and visual cortex (right). The numbers are averaged over data from 5 subjects.

Updating scheme Three kinds of updating schemes introduced here are implemented and compared. Since we saw similar tendency over SENSE and GRAPPA, the data for each case are averaged resulting in Figure 3. Figure 3(left) shows the result of each update scheme when there is minimal motion. Figure 3(right) shows us the case when motion is intentionally conducted.

Discussion

From the reconstructed images in Figure 1, we see that we have larger error for the GRAPPA, though this is mostly due to errors in low spatial frequencies plus some error at the highest spatial frequencies. From Figure 2, we can see that temporal filtering increases effectively removed the alternating shot variations, reducing error and increasing the number of active pixels and time-series SNR for both SENSE and GRAPPA. Even though GRAPPA had higher error in image domain, it produced better results for time series SNR, indicating that these sources of error were somewhat stable across time. Overall, the comparisons between SENSE and GRAPPA was difficult due difficulty in measuring and matching spatial resolution as well as dependencies on reconstruction parameters (e.g. number of iterations, smoothing factor for sensitivity map, and regularization parameter, and in the CG-SENSE algorithm). No single set of parameters led to optimal results for every subject and for every slice. However, for our experiment, we chose each reconstruction parameter for SENSE and GRAPPA that produce reasonable reconstructed image both for motor and visual cortex slices throughout all the data from each subject.

From Figure 3, we can envision that where there is not severe motion, we can apply the sensitivity map or GRAPPA coefficients from the first time point to the rest of the time series data, once we can guarantee that there is not a severe motion at the beginning. Updating scheme 2 (revise coefficients at every time point) produced the best results for the case with severe motion, but the worst results for minimal motion. The updating scheme 3 (continuous updating using a moving average of 5 neighboring time points) seems to work well in both situations and may represent the best compromise.

References

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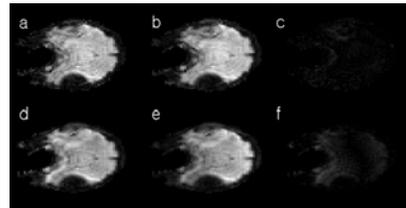


Figure 1. (a,d) fully sampled image (b,e) reconstructed image and (c,f) error maps for (top) SENSE and (bottom) GRAPPA

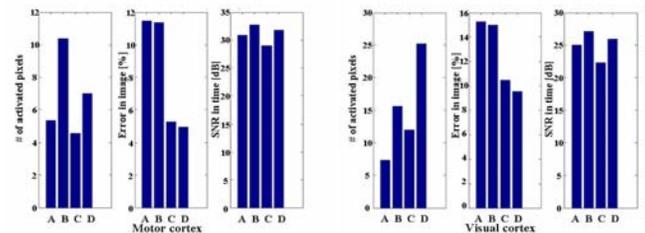


Figure 2. (1st col) # of activated pixel, (2nd col) error [%] in image (3rd col) SNR [dB] in time series of (A, B) GRAPPA and (C,D) SENSE (A,C) before and (B,D) after temporal filtering. (left) motor & (right) visual cortex

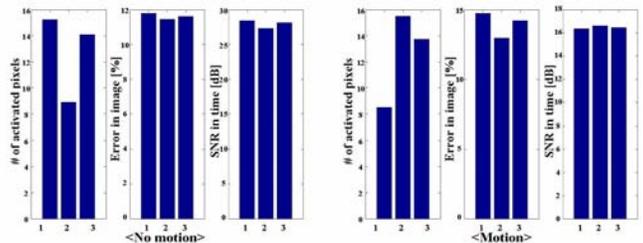


Figure 3. Comparison of different updating scheme by (L) the number of activated pixels (M) error [%] in image (R) SNR [dB] in time series for (left) normal data and (right) for motion induced data