Fast Self-Calibrated Parallel Imaging using Dual-Density Spirals

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INTRODUCTION: Parallel imaging is becoming a widely used technique for improving imaging speed and reducing imaging artifacts. To date, most parallel imaging approaches are based on rectangular k-space sampling and the reduction is applied mostly along the phase-encoding direction. Parallel imaging with spiral imaging has been less widely used due to the lack of efficient reconstruction algorithms. The initial demonstration of spiral parallel imaging was carried out with an iterative SENSE reconstruction [1,2]. More recently, k-space based reconstruction approaches for spiral parallel imaging using techniques similar to GRAPPA [3] have been described [4-7]. Advantages of these approaches include faster reconstruction and no need for accurate sensitivity mapping. This paper describes a self-calibration technique based on slightly increasing the sampling density in the low k-space using a dual-density spiral trajectory design [8]. With the coil-weighting factors derived from central over-sampling, this approach requires no pre-scan of missing k-space data. The method is demonstrated experimentally, generating single shot, high-resolution spiral imaging *in vivo*. Furthermore, a high-resolution BOLD fMRI study is conducted using the method.

METHODS: All experiments are performed on a Siemens 3T Trio equipped with Sonata gradients capable of 40mT/m in 200µs, and are acquired using an eight-channel head array. Spiral gradients are generated numerically using an algorithm that implements variations in sampling density [8]. Gradient design parameters are for a 128 matrix, 256mm FOV, 4 interleaves, and a rise-time of 400µs to avoid peripheral nerve stimulation. The readout duration is 20ms, is sampled at 200kHz and fills the low k-space region (diameter 24) with a density corresponding to the full FOV. The oversampling adds 5ms to the conventional readout. Coil-weighting factors for deriving missing k-space points in the trajectory from multiple coil data, as in GRAPPA [3], are calculated along radial lines as shown in Fig. 1. The fitting routine is performed on the densely sampled region in central k-space. It is assumed that the coil-weighting factors are shift-invariant in the radial direction within each angular band of k-space, and hence the factors calculated in the low k-space can be used in the high k-space. Final reconstruction is by standard gridding and coil combination by sum of squares. For comparison, fully encoded 4-interleave spiral data is also acquired with corresponding parameters. Using the single-shot spiral sequence, a BOLD fMRI study is performed on a human volunteer using a block-design visual-motor task consisting of bi-manual hand flexion during presentation of an 8Hz flashing checkerboard. Sequence parameters used are a TR/TE of 2000/30ms and four 20sec(on)-20sec(off) stimulus blocks.

RESULTS AND DISCUSSION: Image results for a human volunteer are shown in Fig. 2. The top row of images show a fully acquired data set, followed by the resulting alias images (middle) and lastly results of the image reconstruction (bottom). While a significant SNR penalty is incurred at high reduction factors, the reconstructed images show much of the fine details present in the fully acquired data with no apparent residual aliasing. In addition, only 18 k-space bands are used in the reconstruction. As shown in previous results [5-7], relatively few bands are necessary to accurately fit coil-weighting factors to the measured data for spiral trajectory. This observation may infer a high degree of symmetry in the sensitivity encoding. In Cartesian methods, the fitted coil-weighting factors are translation invariant in the k-space. The current work extends this idea by translating the interpolation kernel along radial lines. In this way the self-calibration is possible for spiral parallel imaging and without iterative reconstruction [1,2], as demonstrated by this paper. Results from the fMRI study show high-resolution activation maps and robust BOLD contrast in the timecourse, as shown in Fig 3. Even at a rate 4 reduction, these results do not exhibit a drastic loss in BOLD contrast to noise ratio. The use of a partially parallel strategy for spiral, similar to prior Cartesian methods [3], mitigates the SNR loss typical at high reduction factors.

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REFERENCES: 1. Pruessmann K, et al. MRM 46:4,2001. **2**. Weiger M, et al. MRM 48:5, 2002 **3**. Griswold M, et al. MRM 47:6, 2002. **4**. Griswold M, et al. ISMRM, 2003. **5**. Heberlein K, et al. ISMRM 2004. **6**. Heberlein K, et al. 2nd Workshop on Parallel MRI, Zurich, 2004. **7**. Heidemann R, et al. 2nd Workshop on Parallel MRI, Zurich, 2004 **8**. Sarkar S, et al. MRI 20:10, 2002.

Figure 1. This figure details the reconstruction process. For a single spiral interleave the coil-weighting factors are calculated in the over-sampled region of k-space. In the figure, each solid circle is estimated from two neighboring samples (open circles) along radial projections using one inner point and one outer point. The k-space is segmented into 18 bands where a parallel imaging reconstruction is performed on each band separately.
Figure 2. This figure shows image results in a human volunteer. Sequence parameters are a TR/TE of 2000/4ms, 128 matrix, 256mm FOV.
Figure 3. This figure details results from the visual-motor fMRI study. Average timecourses are generated from activated pixels in the regions indicated.

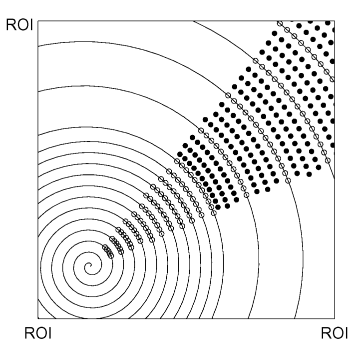

Fig.1

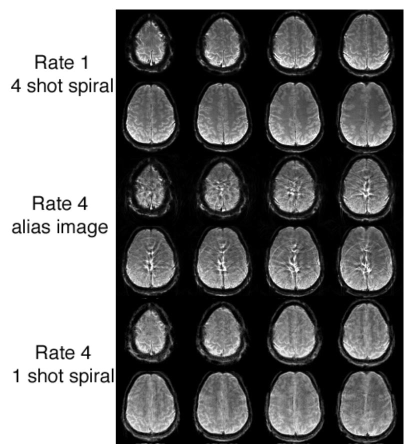

Fig. 2

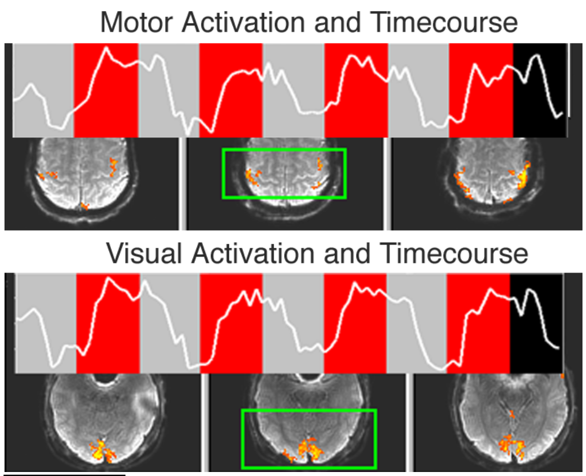

Fig. 3