Consistency Based Ghost Busting (CBGB)

D. J. Larkman[1], R. G. Nunes[1], and J. V. Hajnal[1]
[1]Imaging Sciences Department, MRC Clinical Sciences Centre, Hammersmith Hospital, Imperial College London, London, United Kingdom

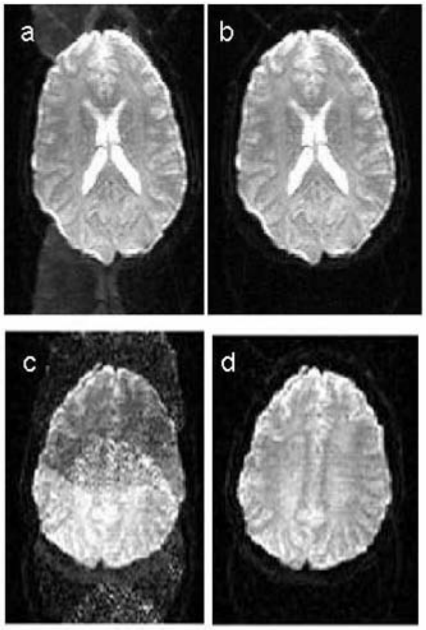
Introduction:

Single shot EPI inherently suffers from Nyquist ghosting if there are any imperfections in the gradient subsystem. Typically eddy current generation is a dominant source of such artifacts. The effect of these imperfections can be corrected in k-space using navigator data acquired as a pre-scan [1]. Such an approach uses valuable acquisition time to collect calibration data and if only collected at the start of dynamic scanning (such as during fMRI) then any drift in the gradient subsystem during the acquisition cannot be accounted for. In the specific case where simultaneous multislice excitations are used [2] conventional navigation methods fail because the k-space data is a superposition of two slices at discrete locations where the parameters required for correction may be different, only a mean correction can be found, this has been shown to limit the utility of such approaches.

Image domain de-ghosting methods can be used where the appropriate phase correction parameters are found by iterative search driven by an image quality metric. Such methods rely on having a significant portion of the image as background or unaliased object [3, 4] and assume that the solution found in the selected area is true for the whole image, neither of which may be the case. The aim of this work is to demonstrate that if coil sensitivity data is available then de-ghosting in the image domain can be driven by a metric based on coil consistency, it can be applied to unaccelerated, accelerated in plane and simultaneous multislice acquisitions with or without inplane acceleration combined.

Theory:

It has been demonstrated that single shot EPI nyquist ghosting can be largely removed by applying a zero and first order phase correction to alternate lines in k-space. The proposed method employs array coil data and minimizes the variation between images reconstructed on a coil by coil basis either directly by 2-D FFT (if no under sampling is used) or using a Parallel Imaging (PI) algorithm, in this case SENSE, where multiple reconstructions are performed N times where N is the number of coils. (Note that this does not require multiple sensitivity matrix inversions but can be achieved via a single inversion and N matrix multiplications). After full field of view, and/or slice separated images are generated the coil sensitivity information is removed from the N images by dividing each by its coil sensitivity leaving N images which, in the absence of artifact are identical subject to noise. Nyquist ghosting produces inconsistencies between these images in the same way that motion artifact has been shown to in other applications. [5]. Calculating a statistical metric, the standard deviation of pixel intensity between coil images, and then summing this over the whole image (or images) gives us a cost function which reaches its minimum when the ghosting is removed and the N coil images are most alike. (standard deviation, variance and max range have all been tested and all perform equally well in this context). The zero and first order phase correction terms which minimize this cost function are found iteratively.



Methods:

The method was explored via simulation and experiment. In the simulations known phase errors were introduced to otherwise perfect data and the results of the algorithm compared to these known errors. This was performed for unaccelerated, accelerated in plane and multi slice cases. A single simulated data set was used as the basis for an exhaustive parameter search to explore the cost function space. Fully sampled, regularly sub sampled and simultaneous multi slice single shot EPI data were acquired on a Philips 3.0T achieva system with an 8 channel head coil. Coil reference data was acquired using a standard FFE sequence. Initial tests used navigation data to determine the correction and then these images were used for coil sensitivity data. This approach was taken to ensure maximum consistency between coil data and target data. In later tests FFE data was used following a simple rigid body registration process to compensate for global shifts. The de-ghosting parameters were found using an unconstrained nonlinear optimization algorithm *(*matlab *fminsearch).* Starting parameters were zero. For the unaccelerated and in-plane accelerated data a search for two parameters was performed. For the multislice data 4 parameters were searched for simultaneously (two for each slice location)

Results:

Exploration of the search space revealed that in the example chosen it has a simple global minimum. In all simulations all phase errors were correctly found within the specified tolerance of the search. For experimental data with well matched reference data (EPI) the first order phase error in the unaccelerated acquisitions deviated by <5% from the scanner navigation based calibration if calibration data were acquired immediately prior to the acquisition. Accelerated acquisitions deviated by a greater amount (10-15%) but no visible errors in the reconstructions could be seen when compared to navigated corrections. The figure shows a) unaccelerated, uncorrected image with the correction in b). c) shows factor 2 in plane accelerated, uncorrected image with the correction in d). Simultaneous multi-slice reconstructions were also free of visible error. FFE coil reference data resulted in increased errors in image slices where there were significant susceptibility artifacts, which is a feature of PI reconstructions but can be offset by increased acceleration where artifacts are reduced. In all cases images were improved with ghosting levels reduced.

Conclusions:

The proposed method provides a robust means of removing Nyquist ghosts from EPI and is equally applicable to in plane and multi-plane accelerations. The method only requires the standard coil sensitivity data needed for PI and so is time efficient during examinations and is not vulnerable to the effects of scanner drift between calibration and acquisition in long examinations.

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