Artifact Reduction based on Parallel Data Acquisition

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Introduction:

Parallel Data Acquisition has given us improved SNR or speed/resolution. This talk is concerned with using multiple receivers to improve the quality of the data collected or to correct data inconsistencies to improve the final images.

Image quality improvement has been a feature of PPI since its start. We have seen many examples of PPI used in EPI imaging to reduce susceptibility based distortions by reducing the readout time and/or echotime. We have also seen improvements in image quality as a consequence of increased speed (e.g. shorter more successful breatholds).

This talk will almost entirely concentrate on emerging applications which have not yet entered the clinic but are taking PPI concepts in new directions. These are applying parallel data acquisition directly to reduce artefacts.

For the purposes of this talk there will be no real distinction made between generalised k-space methods[1], generalised real space methods[2], and hybrid methods[3] of data reconstruction. The differences between these methods are not important within the concepts discussed, so for our purposes if each method can have the same input data then they are interchangeable. In the case where a difference is relevant, or a method is not general, it will be noted.

Data correction: Coherent artifact

At the 2000 ISMRM meeting Kuhara[4] and co-workers presented a concept in which PPI was used to deal with inconsistencies in acquired data, produced by differences between odd and even lines in single shot EPI acquisitions. It was observed that whilst these inconsistencies were grossly damaging in k-space, where their periodicity produces coherent n/2 ghosts in real space, the same inconsistencies smeared over the whole of k-space (with the periodicity removed) result in more benign real space artefacts. The proposed method was to separate fully sampled k-space data into two sets of data each of which only contains odd or even lines (which are consistent). These data are then treated independently as uniformly sub-sampled data to be corrected in a standard PPI algorithm. The two resultant images are then added coherently and the result is a ghost free image.

A potential weakness of Kuhara's approach was that the two images generated from each subset of k-space still had fundamental differences, the reason for the n/2 artifact originally. This example demonstrates a key feature of PPI; It is a simple linear process. Nominally no data is rejected or modified in the process and so if there is a problem with some data then it will remain unless a non-linear step is taken. The next examples introduce the potential for this step to be introduced:
Kellman in 2001 [5] extended this work and described a coherent ghost suppression scheme that uses PPI to solve directly for each ghost allowing flexibility for coherent addition or rejection of the ghosts from the image and hence keep only consistent data if so desired. This makes a more flexible ghost suppression algorithm that works very well for n/2 ghosts and has been applied for n/3 ghosts in GRASE imaging[6]. However, as the ghost number increases the g-factor may result in considerable SNR penalty.

Data Correction: Incoherent artefact

There have been anecdotal reports of clinical users applying PPI speedup factors of two with two coherent averages on scanners where PPI has been made available. This seemingly perverse approach has the useful property of helping to suppress incoherent motion artefact and is the simplest form of motion artefact suppression available in PPI. Conceptually this is similar to the first proposed PPI motion suppression schemes[7]. However, it is not particularly efficient or effective compared to more recently proposed methods such as detection rejection schemes[8] for localised damage in k-space, SMASH Navigators[9] and generalised correction schemes for extended k-space correction. Considering SMASH Navigation as an exemplar of this family of schemes: SMASH Navigation relies on the fact that for a given phase encode line in a fully populated k-space another version of this line can be generated from some or all of the surrounding lines. In the case of SMASH only one line is needed (but the result is critically dependent on the ability of the coils to fit spatial harmonics). If g-SMASH is used then one or more lines can be used relaxing the constraints imposed on the coils somewhat. This newly generated version can then be compared to the original and any differences assigned to motion during the acquisition. If a motion model is available then corrective action can be taken and the next line investigated, in this way error correction can be propagated across k-space. Currently simple rigid body corrections are used.

From this work a more general approach was developed, self consistent optimisation. This approach is easiest to describe using fully sampled data, although is applicable to undersampled data also. A FFT of the acquired data from a single coil produces an image modulated by the coil sensitivity function. If we reconstruct using PPI then this coil modulation can be removed or modified (depending on the denominator used to remove structural content from the sensitivity data). The process can be repeated for the k-space of each coil and the result will be n images which should be identical, subject to noise fluctuations. In the presence of motion these images are not identical, the artefact will appear at the same spatial locations in each image but with different signal intensities based on the proximity of the moving part to each coil (these motion "ghosts" are modulated by the coil sensitivity appropriate for their origin location not the location they now appear at). This allows us to construct a minimisation function to make the versions consistent:

$$E = \sum_n \left| I_n - I_{full} \right|^2$$

Here I_n is the reconstructed image from coil n and I_{full} is a reconstruction using all coil information. With no artefact this function is zero (subject to noise). Motion can now be represented by a number of unknowns in k-space, the natural domain for a time evolving artefact. These unknowns are iterated subject to minimising the function above. Interestingly, the unknowns can be applied to the object or the coils, in general they are applied to the coils resulting in a modified sensitivity data set which successfully produces an artefact free object. This type of correction approach has been demonstrated for bulk motion of the head and pulsatile motion of blood in the aorta[10].

Conclusions.

SNR improvement, Speedup/Resolution enhancement is a small subset of the applications of array coils. Array coils have now become an integral part of the the spatio-temporal encoding system. The increasing numbers of coils becoming available mean that in general we have multiply sampled our data. Exploiting this oversampling and using it to maintain consistency should continue to reveal new applications for array coils in the area of artefact control.

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