Parallel Imaging and MR Motion Correction

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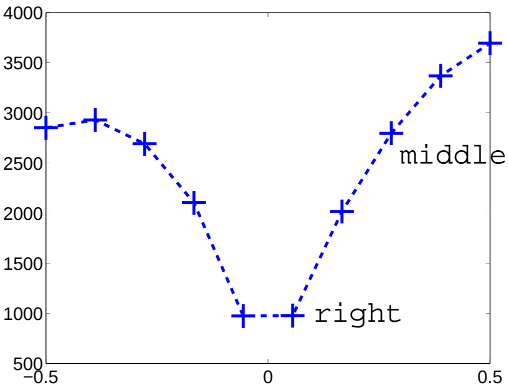
Introduction. We are interested in how the extra information from multiple coils can be used to help in motion correction, building on previous work [1, 2]. We are able to correct for general known motions using a matrix formalism. We discuss the theoretical spatial distribution of the coils, how this spatial distribution can be quantified, and how the additional information from multiple coils can be used to determine motion. We construct an energy for motion from the coil data, and show that it can be used to correct motion.

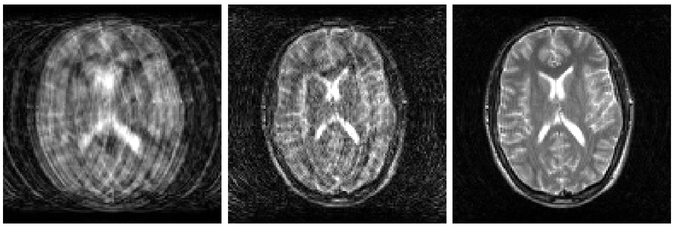
Theory. The main idea is to use spatial dependence of coil sensitivities as a measure of displacements. A template algorithm is then: *Step 1*: produce a guessed motion; *Step 2*: correct the data using for this motion; *Step 3*: assess the data using an energy, here from parallel MR. *Step 1* is handled by an optimisation algorithm.

Motion Corrections (Step 2). The motion corrupted image s can be written $s = \gamma s_0$ where s_0 is the perfect image and γ is a large matrix that encapsulates: the motion at each time point, Fourier transform to k-space, the k-space sampling at each time point, and Fourier transform back to the image domain. The matrix γ is large but the system can be solved efficiently using conjugate gradient methods without explicit calculation of all elements of γ (for more details, see [2]).

Coil spatial patterns and displacements (Step 3).
We introduce a general motion energy E as a similarity between views s_i from different coils (coil sensitivities c_i), $E = \sum_{ij} e(s^{c_i}/c_i, s^{c_j}/c_j)$ where e is some similarity between images, here $e(x,y) = |x-y|^2$. Thus, the energy would take the form $\sum_{x,i,j} |r|^2 |c_i(x+u)/c_i(x) - c_j(x+u)/c_j(x)|^2 \approx K|u|^2$ for small displacements u, where K is a function of the coil spatial patterns which is zero when the coils are identical; r is the image. We plot here the energy in a simulation where the motion is a 1-parameter (t) nonrigid radial deformation $\rho \mapsto r_0(\frac{\rho}{r_0})^{1+t}$ (ρ: distance from the center of the image). The motion happens in 8 shots, thus there are eight parameters t_k chosen so that the motion describes a sort of pulsation (here $(t_k) = (0, 0.2, 0.4, 0.5, 0.5, 0.4, 0.2, 0)$), and 6 coils, which here have a Gaussian shape. The t_k are varied in a controlled way as a function of one parameter, which is the x-axis in the plot, the y-axis is the coil energy. Computationally it took approximately 3 mins. to compute each energy. Some of the corresponding images, computed using our matrix formalism, are displayed in the second figure.

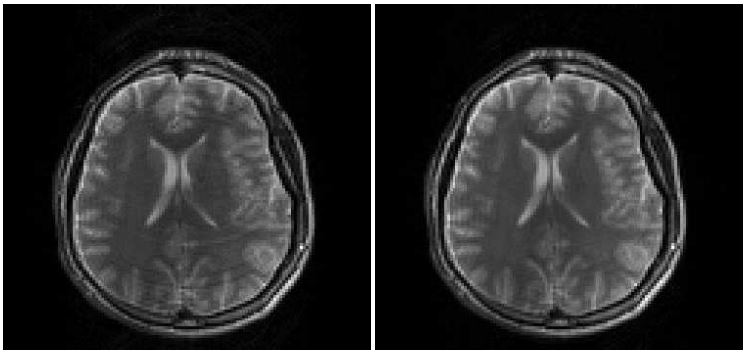


The image on the left shows the motion corrupted image when $(t_k) = 0$ for all k, the middle one corresponds to $(0, 0.28, 0.5, 0.62, 0.62, 0.5, 0.28, 0)$, where the image on the right is the image corrected using the correct t_ks, we do not display the original image, as the motion corrected one is essentially identical.



Coil spatial distributions. The formula above for E would imply that the coil separation should be as large as possible. This of course has to be counterbalanced to make the final SENSE reconstruction of best possible quality. We define the optimal coil positioning as the one which minimises the condition number κ of the general SENSE equation $s^c(x) = c(x)r(x)$ for all voxels x and coils c. This number, in idealised circumstances, is the max to min ratio of the sum over coils of squared coil sensitivities over the field of view: $\kappa = (\frac{\max_x \sum_i |c_i(x)|^2}{\min_x \sum_i |c_i(x)|^2})^{1/2}$.

Results and Conclusion. The energy can be interpreted as a sum of squares, thus efficient optimisation for nonlinear least-squares can be used. Here we used the nonlinear least squares (Levenberg-Marquardt based) from Matlab's (The MathWorks, Inc.) optimisation toolbox, and, optimised over rigid body motions on an in vivo example, acquired with 5 coils, in a Philips 1.5T scanner. The results are displayed in the two last figures, the figure on the left is the motion corrupted image where the volunteer had moved his head, ghost edges are clearly visible above and below the ventricles. These have been eliminated in the optimised image on the right. For this optimisation we used a fast approximate version of the matrix inversion. This results in fast optimisation (5 mins. here). We have shown that motion correction of complicated motions is a realistic prospect, and that parallel MR can be an effective tool in this context.



References

1. D. Atkinson, D. Larkman, J. Hajnal, P. G. Batchelor, and D. L. G. Hill. Coil-based artifact reduction. *Magn. Res. Med.*, 2004, to appear.
2. P. G. Batchelor, D. Atkinson, and D. L. G. Hill. A matrix framework for MR motion correction, to appear, Proceedings MIUA 2004.