Automatic Motion Correction Using Prior Knowledge

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Introduction

Motion during the acquisition of an MR scan can cause a blurring and ghosting in the image. In clinical applications there are often many repeat images of a patient some of which are motion free, and others that may contain motion artifacts. Serial studies such as a cancer screening program or the monitoring of diseases with slow progression provide repeated measures on the same subject. Perfusion and dynamic sequences repeatedly image the same anatomy to observe contrast changes. Many protocols acquire two or more data sets prior to averaging in order to improve the image signal to noise ratio. Routine examinations image the same anatomy with a range of contrast sequences e.g. T1 weighted, T2 weighted.

Thus for many patients there exists a large quantity of information. Although the scans may be individually reported, currently the data is rarely combined in order to reduce motion artifacts. The method of projection onto convex sets (POCS) [1] uses the tissue/air boundary from one image to construct an image-domain mask used in an iterative scheme to reduce artifacts in another image. The method proposed here uses all of the available information (rather than a mask). Another key feature of our method is that the motion is determined in the spatial frequency domain and we do not require many time consuming 2D Fourier transforms of the whole data.

Methods

A spin echo sequence (TR/TE = 500/10 ms) was used to image a volunteer lying still and again with a slow nodding throughout the scan with an additional quick nod mid-way through the scan. The complex k-space was saved in each case and the data size reduced to 128x128. The entropy of each image was calculated [2,3] and the image with the lowest entropy was chosen as the good quality, or reference image. The k-space of the corrupted image was rotated using a shearing method [4] in 0.5° steps from -8° to 8° and the rotated k-spaces stored.

Each phase encode line in the reference and motion corrupted data was compared individually to determine first the relative rotation angle and then the translation. Rotations of the subject cause a corresponding rotation of k-space and translations impart phase ramps to the k-space. Identification of the rotation angle was made using only the modulus information and hence was not affected by translational motion (the modulus is independent of phase). The procedure was as follows:

For each phase encode line *l*, form the row vector *G* that contains all the k-space points in line *l* of the good image. Similarly form the row vectors B_j from the stored rotated k-spaces of the bad (motion corrupted) images. Here *j* denotes each of the 17 stored k-spaces at 0.5° steps from -8° to 8°. The focus criterion F_j was evaluated at each angle *j* where;

$$F_j = \frac{\sum(|B_j| - |G|)^2}{\sum(|B_j|^2 + |G|^2)}$$

Here the modulus and multiplication operators function element-by-element on the vector data and the summation adds the resulting vector elements. The angle $a=j$ that minimises the focus criterion is taken to be the correct angle. To determine the translation in the frequency encode direction we used a modification of the cross-spectrum method [5]. The row vector ψ is calculated from the data using;

$$\Psi = \frac{B_\alpha' G}{|B_\alpha G|}$$

where ' denotes complex conjugation. ψ was then zero padded, in this case to 5 times its original size, and 1D Fourier transformed to the image domain. The position of the maximum gives the relative frequency encode displacement between the two lines. The phase at this point (φ) gives the phase encode shift *d*, $d = \varphi / (2 \pi l)$.

Results

Figure 1 shows the reference image (entropy 412) and the motion corrupted image (entropy 434). Computation and storage of the rotated versions of k-space took 11 seconds on a 300MHz Sun Ultra 30 and the complete algorithm took 27 seconds. After applying the correction scheme, the corrected image shows reduced ghosting and blurring. The pattern of rotation changes found by the algorithm correspond with the instructions given to the volunteer.

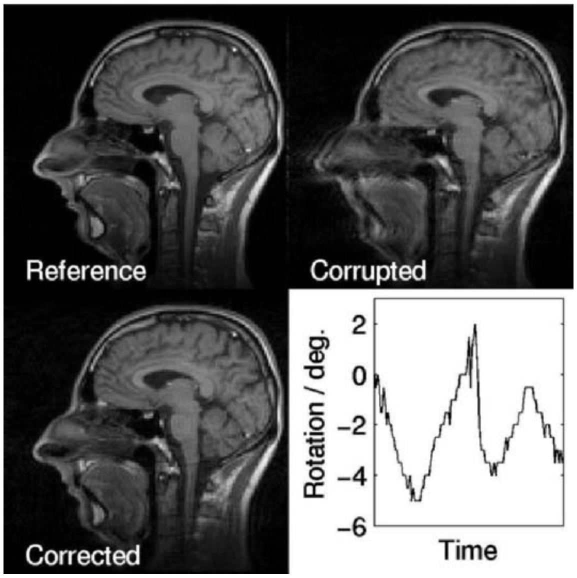

Figure 1 showing the stationary volunteer (reference), motion corrupted and the corrected image. The graph plots the rotation angle found by the algorithm as a function of scan time.

Discussion

We have demonstrated a rapid means of using an artifact free image to determine the motion that corrupted a separate image. The selection of the better quality data can be made automatically using an entropy criterion [2]. Given two motion corrupted data sets, it may be possible to use entropy to assemble one good quality image [3]. In our method, the comparisons between the two data sets are performed in the spatial frequency domain and do not require repeated 2D Fourier transforms of the whole data set. Apart from the initial entropy assessment, all Fourier transforms are 1D and for a 128x128 image, the motion was found and correction applied in under 30 seconds. Unlike the POCS method, we do not need to determine a region of support that is accurately aligned spatially with the corrupted image data. Furthermore, the calculation of translational motion in our scheme is not iterative and thus is rapid.

The good data is used to determine the rotation angle and translational shifts but the k-space from the good data does not form part of the corrected image. The corrections applied to the motion corrupted data are based on a motion model. For these reasons, we expect the technique to offer some robustness to noise and to any differences between the reference and corrupted images (e.g. an enhancing tumour).

References

[1] M. Hedley et al. IEEE Trans. Med. Imag. 1991;10:40-46.
[2] D. Atkinson et al. IEEE Trans. Med. Imag. 1997;6:903-910.
[3] C. Weerasinghe et al. Signal Proc. 2000;80:867-881.
[4] W.F. Eddy et al. Magn. Reson. Med. 1996;36:923-931.
[5] B.S. Reddy et al. IEEE Trans. Imag. Proc. 1996;5:1266-1271.