

Multi Channel Self Navigated Motion Correction

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INTRODUCTION

In this work we explore the possibility of self navigation in a conventional TSE sequence using the correlation of adjacent sets of k-space lines. The method relies on the assumption that very little motion occurs during a single echotrain and that an extended FOV in the phase encoding direction has been acquired. Further, it requires that the phase encoding order of each echotrain be related by a simple shift in k-space. If a multichannel receive coil is used then the FOV constraint can be relaxed.

THEORY

Rigid-body motion between two images m_1 and m_2 can be detected using cross-correlation. If m_2 is just a shifted version of m_1 (with offsets x_0 and y_0) then the cross-correlation function $C(k_x, k_y)$ is a Dirac delta function (offset from the origin by x_0 and y_0) convolved with the Fourier transform of the magnitude squared of $M_1(k_x, k_y)$. The effect of $\Im\{[M_1(k_x, k_y)]^2\}$ can be removed if we use:

$$C_w(k_x, k_y) = e^{i\arg[C(k_x, k_y)]} = e^{i(k_x x_0 + k_y y_0)} \quad [1]$$

where $\arg()$ is the argument function that extracts the angular component of a complex number. Now consider a sampling function that selects N_e equally spaced lines for the L^{th} echotrain:

$$S_L(k_x, k_y) = \sum_{j=0}^{N_e-1} \delta(k_y - (L + jN_{\text{et}})\Delta y) \quad [2]$$

where N_{et} is the total number of echotrains and Δy is the voxel spacing. If the same echotrain is sampled a second time after some delay, the correlation between the same two echotrains can be written as:

$$c_L(x, y) = N_e \sum_{j=0}^{N_e-1} \delta(x - x_0, y - jN_e\Delta y - y_0) e^{i\pi\left(\frac{2L}{N_{\text{et}}} + N_e - 1\right)j} \quad [3]$$

The effect of correlating the same set of equally spaced measurement lines is that the Dirac delta function is replicated N_{et} times (the number of echotrains) with a phase that depends on the shift (L) of the k-space measurements. If the motion in the y-direction occurring between two acquisitions of the same subset is less than $\frac{1}{2}N_e\Delta y$ then the motion can still be accurately quantified. In this work, we carry this observation one step further to show that it is possible to detect motion between two adjacent sets of k-space measurements. Consider what happens if we physically shift each k-space line in the first echo train by $\frac{1}{2}\Delta k_y$ and each line in the adjacent echo train by $-\frac{1}{2}\Delta k_y$. If a cross correlation is then taken, the correlation function described in Eq. [1] is modified as:

$$C_w(k_x, k_y) = e^{i\arg[C(k_x, k_y)]} = e^{i(k_x x_0 + k_y y_0)} e^{i\phi_{\text{err}}(k_x, k_y)} \quad [4]$$

where $\phi_{\text{err}}(k_x, k_y) = \phi_1(k_x, k_y - \frac{1}{2}) - \phi_1(k_x, k_y + \frac{1}{2})$ is the phase error term and is caused by the fact that adjacent k-space lines are not perfectly correlated. The phase function $\phi_1(k_x, k_y) = \arg(M_1(k_x, k_y))$ is the phase of each k-space point in the absence of any motion. As the measured FOV increases, the correlation between adjacent k-space lines increases and the phase error term is reduced. In practice we will use a finite FOV and so there will always be some residual phase error. Any linear component of the phase error term will cause a shift in the delta function and will directly affect the accuracy of the motion estimates. The higher order terms of the phase error tend to blur and distort the Dirac delta function making it difficult to accurately locate the peak. To the extent that the phase error term is small, it is then possible to detect the motion between adjacent sets of lines. This constraint on the FOV can be significantly relaxed if a multichannel coil is used to receive data. In this case, adjacent lines from each coil can be used to produce a motion estimate and an average value can be used.

RESULTS AND DISCUSSION

2D TSE head images at various field of views were obtained on a Siemens Trio 3T MRI scanner from a volunteer using a single and multi channel head coil. Motion artifacts were introduced by applying varying linear phase shifts to each echotrain taking into account the slice interleaving and phase encoding order used to acquire the images. The images were acquired with a 0.5mmx0.5mmx5mm resolution, TR=3s, TE=13ms and 11 echoes per echotrain. The effect of varying the FOV on motion artifact reduction is demonstrated in Figure 1. When the FOV approaches the size of the object, the self-navigating technique with a single receive channel is not able to fully correct the motion artifacts (Fig. 1a). However, if we acquire a FOV of 126% of the object size (Fig. 1c), many of the motion artifacts are eliminated. With a larger FOV of 171% of the object size almost all the motion artifacts have been removed. It has been assumed that the typical motion of an object will follow some relatively smooth time course. This smooth time course was achieved by multiplying the Fourier Transform of the detected objects motion in time by a low-pass filter. Figure 2 shows the reduction in FOV required when a multi channel receive coil is used. In this case a FOV of just 105% of the object is sufficient to remove the motion artifacts to the same degree as the FOV of 171% in the single channel receive coil case. The error of the detected motion for the multi channel receive coil is shown in Figure 3. For this TSE data set, the maximum error is less than 0.4mm in either direction. If the object also exhibits small rotations less than two degrees between successive echotrains in a slice, the motion correction is still successful. For larger rotation angles there is still a reduction to the motion artifacts using the self-navigation technique, just to a lesser extent. As a result, for cases where there is large object rotations, a detection and correction for the rotations should be done prior to the motion correction.

CONCLUSION

This work provides a demonstration that rigid-body translational motion that occurs during the acquisition of MRI data can be detected, quantified, and corrected using selfnavigation. This is the case when subsets of k-space measurements are acquired closely spaced in time such that motion occurs between subsets, and that there is sufficient support external to the object in the acquisition space so that adjacent subsets of measurements are correlated.

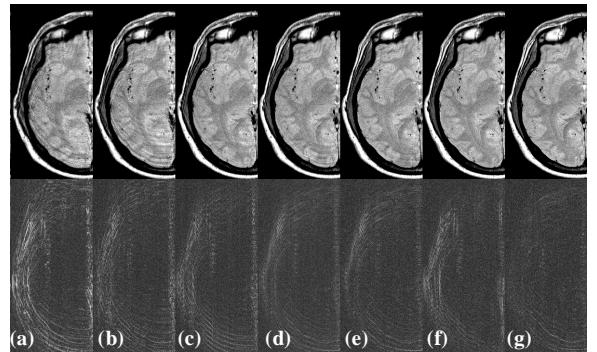


Figure 1. Single channel TSE motion corrected images with varying FOV. The top row contains images corrected using the proposed self-navigating technique and the bottom row shows the difference images. Each column represents a different FOV with (a) 105%, (b) 116%, (c) 126%, (d) 138%, (e) 149%, (f) 160%, and (g) 171% of the objects size.

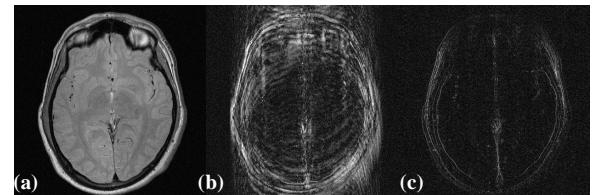


Figure 2. 4 channel receive coil TSE motion corrected images. The FOV in the phase encode direction is just 105% of the object size. The original image is shown in (a) with a difference image of the motion corrupted case in (b). The difference between the motion corrected image and the original is shown in (c).

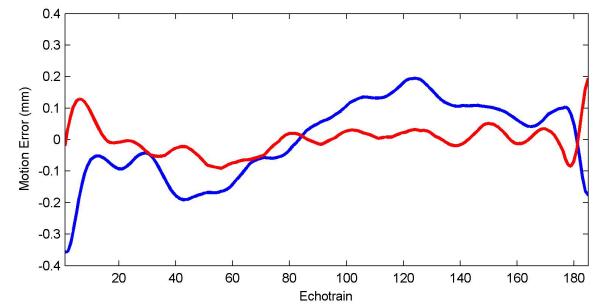


Figure 3. Motion tracking error on TSE head images. The blue line represents the error in the phase encode direction and the red line is the error in the readout direction. The maximum error in either case is less than half a millimeter.