A Method To Eliminate Motion-Related Ghosting Artifacts From Images Of Active Devices During Parallel Imaging

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Introduction: In MRI-guided interventional procedures it is important to be able to precisely visualize the interventional device (such as a catheter or guidewire) in relation to adjacent tissue. To achieve this goal, active devices (devices that contain receiver coils whose signal can be collected separately from the other coils in the MRI scanner) are used in combination with MR surface coils. The image of the slice of interest, formed from the MRI surface coils, is blended with a color image formed from the active device alone [1].

Parallel imaging reconstruction methods (TSENSE, GRAPPA) are used to provide real-time reconstructions of the surface-coil image from under-sampled data. But since the device-channel image is created from data collected by a single coil, such parallel imaging techniques can not be used in reconstructing it. Consequently, when reconstructed from under-sampled data using view-sharing, the device-channel image displays ghosting artifacts along the phase-encoding coordinate [2] as seen in Figure 1 (left). The right image in Figure 1 shows the de-ghosted image produced by our method. This ghosting is caused by periodic discontinuities along the phase-encoding coordinate in Fourier space caused by adjacent lines in k-space having been collected in different time-frames while the device is in motion.

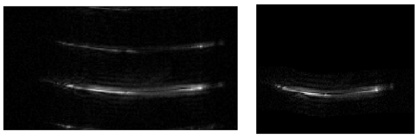

View-shared De-ghosted

Figure 1

The ghosting artifact is exacerbated in multi-slice imaging. Figure 2 shows the order in which Fourier data is collected in a multi-slice, parallel imaging system (with an undersampling factor of D=3 and slices numbering L=2). The vertical axis represents the phase-encoding index of each slice. In the first frame slice 1 is excited and every third k-space line is collected (n_k=1,4,7,...), in the second frame slice 2 is excited and the same set of k-space lines are collected (n_k =1,4,7,...). In the third frame slice 1 is excited and the adjacent set of k-space lines are collected (n_k=2,5,8,...) and so on. As the number of slices being imaged is increased the ghosting artifact is exacerbated as the time between adjacent k-space lines in a particular slice is increased and so is the likelihood of motion. In this paper we exploit the sparsity of the device channel image to eliminate the ghosting artifact. We describe our method and present *in vivo* results.

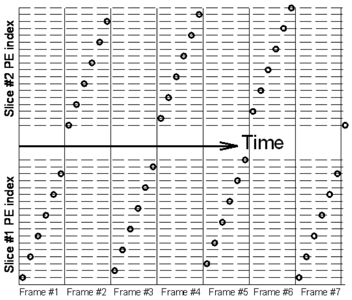


Figure 2

Methods: It is reasonable to assume that the motion during a single frame is negligible compared to the motion between frames. The image reconstructed from data from a single frame is undersampled by a factor D and therefore displays periodically repeated image copies (as seen in Figure 4). In particular, every column of the Fourier-undersampled image is periodic with period Ny/D (where Ny is the number of pixels of the image along the phase-encoding direction). The deghosting problem is equivalent to simply determining which (D-1) of the periodically repeated image copies (of the temporally local Fourier-undersampled image) to discard by zeroing out the corresponding pixels.

This problem can be column-wise decoupled so that the deghosting problem is solved for each column separately. Let us denote the signal along a column of the device image at time t to be the complex function $f_t(y)$. For pure translational motion i.e. $f_t(y)=f_0(y-y_t)$, the deghosting problem can be solved by considering a low-pass-filtered, view-shared image and identifying the period of the column which contains the most energy. This is illustrated in Figure 3 for an undersampling factor of D=2. Figure 3 (a) shows the true signal in frames A (dotted) and B (dashed). Figure 3 (b) shows the image formed from data from frames A and B (dotted) and the view-shared image which is the sum of the two individual undersampled images (solid line). Because there is translational motion between the frames, the two signals do not add to produce a clear dominant peak and the correct choice of period is indeterminate. On the other hand, as shown in Figure 3(c), after low-pass filtering the two signals add to produce a clear dominant in the correct period. The de-ghosted signal is obtained by zeroing out the unwanted period in the undersampled signal.

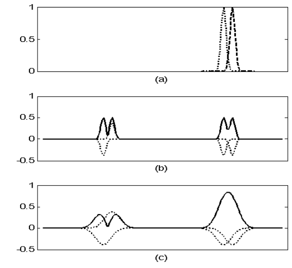
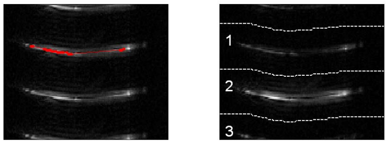


Figure 3

While this method works for some looped coils, unfortunately loopless active devices such as shown in Figure 1 have a coil sensitivity with a rapidly varying phase. Consequently slight motions in the device can cause large changes in the phase of the signal and the motion from frame to frame can not be modeled as pure translation. Fortunately in this case we can exploit the continuity of the device shape instead. In particular we use the fact that the index of the correct image copy is highly correlated between columns because the device is continuous. We first compute the center-line of the active device in the under-sampled image, as shown in red in Figure 4 (left), by computing the location of the peak in the first Ny/D pixels of each column (along with some unwrapping of this center-line to enforce continuity of the device). This center-line is used to divide each column of the view-shared image into D periods --- labeled 1, 2 and 3 in Figure 4(right). For each column of the undersampled image with sufficiently bright pixels ("good columns"), the label of the period in the view-shared image with the maximal energy ("optimal period label") is determined. To enforce the continuity of the device, this optimal period label is subject to a majority vote over all the good columns. In the case of Figure 4, the optimal period label is 2. Finally the other (D-1) periods (1 and 3 in Figure 4) are zeroed out to produce the de-ghosted image as shown in Figure 1 (right).



Undersampled Viewshared

Figure 4

Results: The method was successfully tested *in vivo* in a pig using a loopless active guidewire. A multi-slice (L=3) imaging mode was chosen and undersampling factors of D=2, 3 and 4 were used. Figure 1 (right) shows a representative de-ghosted device-channel image. The method was also successfully tested on an active needle with multiple looped coils as shown in Figure 5. SSFP imaging sequences were used on a 1.5T Siemens Espree scanner (Siemens Medical Solutions, Erlangen, Germany).

Discussion: The method works while the active device is oriented in a wide variety of configurations in the imaged plane. But there are certain pathological cases in which de-ghosting is mathematically impossible --- such as when the device is oriented strictly along the phase-encoding direction and the signal folds onto itself. More generally as long as the support of the active device signal along every column is less than Ny/D pixels de-ghosting will be possible.

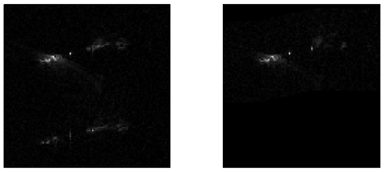

Viewshared De-ghosted

Figure 5: Active needle with looped coils

Conclusion: We have presented, and successfully tested, a method to eliminate the ghosting artifact from the active device image during parallel imaging. This will enable the use of high acceleration factors during real-time imaging without compromising the active device signal.

References:1. Guttman et al *JCMR* 4:431-442, 2002 2. Bock et al *MRM* 55,6:1454-1459 2006