# Improved Accuracy of Shift Calculations through Appropriate Filtering of High Resolution Navigators

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**Introduction**: Navigators [1] are used to detect translation that can be used to phase-correct corresponding data frames with cross-correlation or a least-squares approach [2]. The quality of the corrected image is a function of how finely the object shift can be resolved and how accurately the shifts can be calculated. While the precision of these values depends on the navigator spatial resolution, the accuracy depends on the signal-to-noise ratio (SNR). When attempting high precision, (e.g. in high-resolution imaging), the SNR can be quite low. In this work, we analyze the effects of filters on signals before cross-correlation and, specifically, show that particular filters, when applied to navigators, improve the accuracy of the measured shift and, thus, the quality of the corrected image.

**Theory/Methods:** Shift calculation is a function of navigator phase difference. Phase noise (and therefore phase difference noise) is proportional to the inverse of the signal magnitude. The location of the peak of the cross-correlation of two signals yields the shift. A matched-filter optimally balances the phase noise by weighting each sample in k-space by the signal magnitude, i.e. it maximizes the SNR at the peak of the cross-correlation. Despite this, we experimentally found that matched-filters do not always yield improved shift calculations. In fact, in many cases, they caused worse shift calculations. Two experiments will be discussed here. The first experiment is a simulation used to gain insight on why matched-filters may result in worse shift calculations. In this simulation, multiple pairs of k-space signals were created. Noise was added to each signal, each pair was filtered and the peak of the cross-correlation was found. The filters used resulted in signals with different k-space second moments. Since the second moment in k-space is proportional to the second derivative of its Fourier transform at the origin, we know that k-space signals with a higher second moment have greater curvature in the object domain. The second experiment corrected k-space acquisitions based on the shifts that were calculated using filtered and unfiltered navigators. Motivated by the first experiment, filters with a larger second moment in k-space were used and the results using unfiltered and filtered navigators were compared. The three filters studied were (1) a matched-filter, (2) a low-pass filter and (3) a Gaussian filter. In each case, a standard 2DFT image was acquired and each phase encode (PE) was followed by a navigator. The navigator was implemented using a cylindrical excitation and a 1-D readout along the excitation axis. Each navigator was cross-correlated with a reference navigator and the peak of the cross-correlation was taken to calculate the shift of each PE. These shifts were used to correct (through phase multiplication) the acquired PE. Fourteen scans were performed with various objects and scan parameters.

**Results:** Figure 1 shows the results of the first experiment. As k-space signals get narrower, their cross-correlation flattens. This results in a decreased resistance to noise. A matched-filter generally has a flattening effect on low frequency signals. These results suggest that using a filter that reduces the noise without flattening the cross-correlation signal would result in fewer shift calculation errors. The second experiment showed that the matched-filter was inferior to the other filters. While the matched-filter can result in improvements (see Figure 1), over fourteen scans the matched-filter resulted in an average of 109% *more* shift calculation errors than when unfiltered. The LPF had 51% less errors and the Gaussian filter had 57% less. Figure 2 shows a navigator (unfiltered and after matched-filter and Gaussian-filtering), the corresponding cross-correlations and the corrected images based on the calculated shifts.

**Conclusion:** While the matched-filter improved the SNR of the navigator and the resulting cross-correlation, the flatter signal made it more likely for an incorrect peak to be selected. This resulted in more errors in shift calculations and, therefore, more motion artifacts. We've shown that with proper filtering, shift calculations are more accurate and image quality is improved.

**References:** (1) Ehman, R.L., *et al., Radiology,* **173**:255, 1989, (2) Wang, Y., *et al., MRM* **36**:117, 1996.

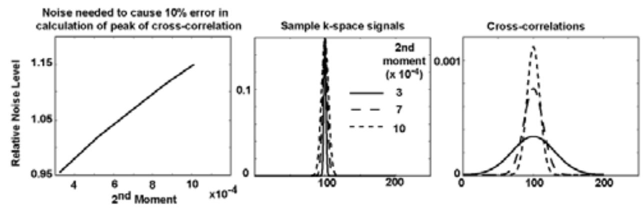


**Figure 1:** (*Left*) Relative noise level needed to cause a 10% error in the calculation of the peak of the cross-correlation of two signals. (*Center*) Three k-space signals after filtering. (*Right*) Their resulting cross-correlations. Signals with a higher $2^{nd}$ moment (wider in k-space) result in narrower cross-correlations and these are shown to be more resistant to noise. These results suggest that using filters that will increase the $2^{nd}$ moment of the signal may be just as important as improving the SNR at the peak of the cross-correlation.

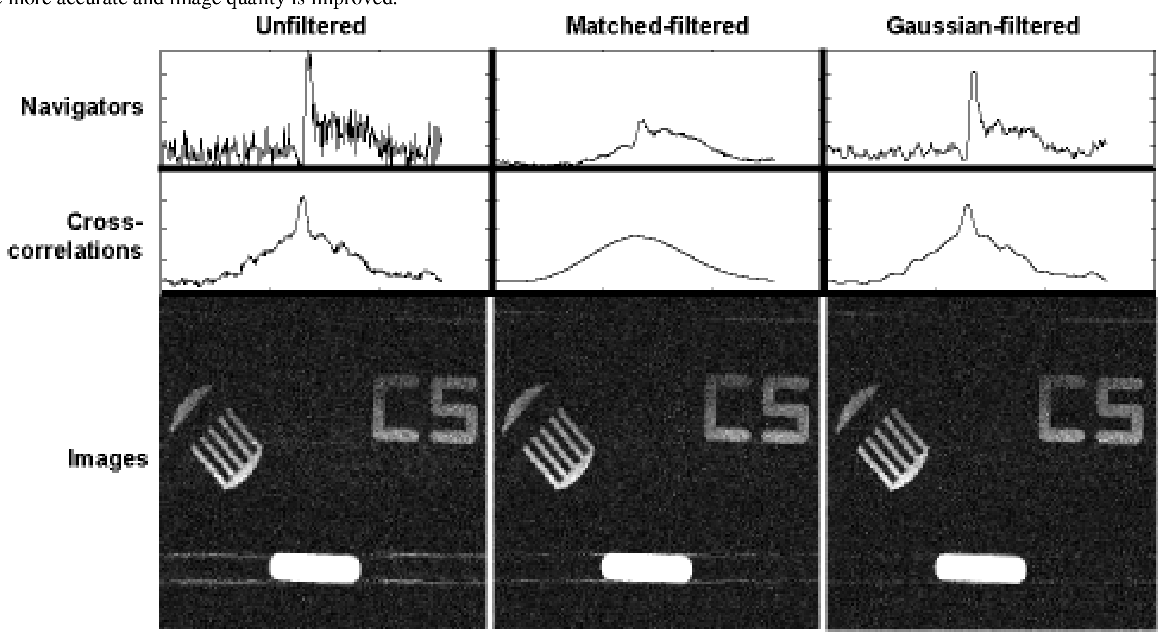


**Figure 1:** Unfiltered, matched-filtered and Gaussian filtered navigators, with their corresponding cross-correlations and the images corrected using the shift values calculated from the corresponding navigator sets. There were 97, 85 and 8 errors (out of 256) respectively for the above cases. Significantly less banding of the solid bar, the sharper comb and the reduced background noise indicate the reduction of motion artifacts with the improved filter.