Filtering and Phase-Correlation Based Registration of Dynamic Contrast Enhanced Magnetic Resonance Images

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Introduction: Previously used to characterize tumor vascularity, dynamic contrast-enhanced magnetic resonance (DCE-MR) imaging is now frequently used to identify and study inflammation of atherosclerotic plaque. By examining the tissue uptake of the contrast agent over time using signal intensity curves generated from the acquired dynamic series it may be possible to draw inferences regarding the composition and neovasculature of the plaque. In order to compute accurate time-signal intensity curves all the images in the dynamic series need to be properly aligned. However due to patient motion and the low signal-to-noise ratio (SNR) arising from the rapid acquisition characteristic of DCE-MR imaging, there can be significant misalignment that can corrupt the analysis. Thus de-noising and image registration procedures need to be implemented prior to analyzing the dynamic image series. This study examines anisotropic diffusion filtering and phase-correlation based registration for aligning DCE-MR data.

Methods: The image processing techniques were tested on a set of DCE-MR images of the right common carotid artery of 20 patients. The images were acquired using a black blood, double-inversion recovery, turbo spin-echo sequence. The images were filtered with three iterations of a non-linear anisotropic diffusion filter (P. Perona and J. Malik, IEEE Pattern Anal. Machine Intell., 1990). The anisotropic filter uses an adaptive diffusion function to smooth the image, inhibiting smoothing across edges and promoting it in homogeneous regions of the image. The filtered images were cropped to an 80x80 pixel region surrounding the artery. The cropped regions were aligned using phase-correlation based registration. The phase-correlation method uses the Fourier-shift theorem to detect motion between consecutive images in the time series. A Kalman filter was also included in the registration process to attenuate noise effects. In a second scheme, instead of registering consecutive images, the average of 5 successive images was computed and the gradients of the average image and the current image were registered using the phase-correlation method with Kalman filter. The improvement to the alignment of the series was quantified using a correlation coefficient (CC) measure. The CC between consecutive images were computed and then averaged to generate a mean CC value for the entire series. Mean CC values were computed for the original data set, after filtering with the anisotropic filter, after registration using phase-correlation and the Kalman filter and finally after averaging and registration of the gradients with phase-correlation and Kalman filtering. A one-way ANOVA analysis of the mean CC was used to compare the performance of the various processing methods.

Results: Application of the anisotropic filter resulted in smoothing of the homogeneous regions of the image while still maintaining the edges as shown in Fig. 1(b). Registration of the filtered and cropped image using phase-correlation with the Kalman filter is shown in Fig. 2. The box plot of mean CC values at each processing step is displayed in Fig. 3. The ANOVA analysis showed that phase-correlation registration with Kalman filtering produced significant improvement in the mean CC compared to the un-filtered, un-registered data ($p < 0.001$). There was no statistically significant difference between phase-correlation registration of the images and registration of the gradients of the average images ($p > 0.05$).

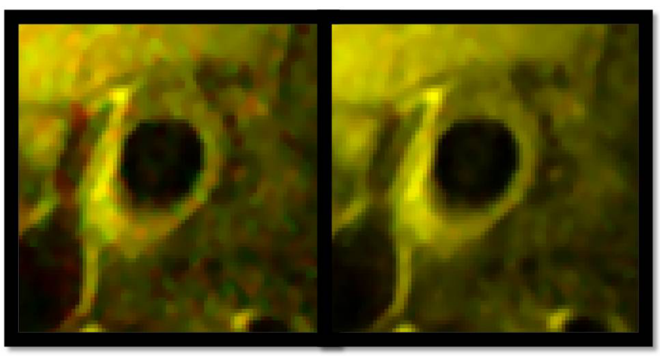

Fig. 2: Cropped section from two consecutive frames overlaid (a) prior to registration and (b) after registration with phase-correlation and Kalman filtering showing the improved alignment of the images.

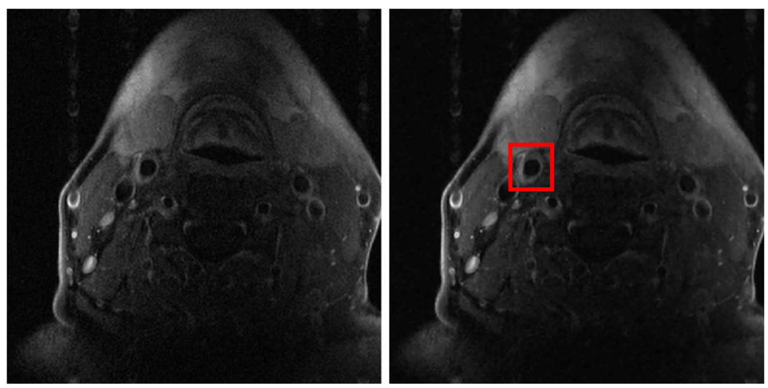

Fig. 1: *(a) Original DCE-MR image and (b) after filtering with anisotropic diffusion filter. Red square marks the cropped region used for registration.*

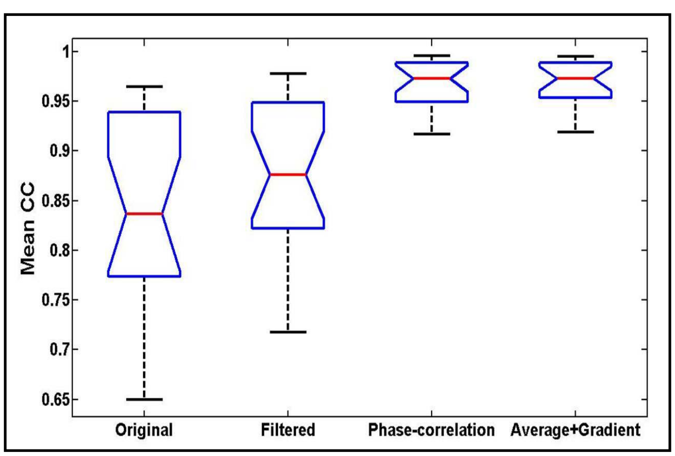

Fig. 1: *Box plot of mean CC distributions across the sample population for unregistered data, after each processing step.*

Conclusion: In this study we examined a filtering scheme and registration method for processing DCE-MR images. The anisotropic diffusion filter smoothed the images while still preserving the edges, especially the lumen boundary, thus retaining the advantages of the black-blood acquisition. Registration with phase-correlation and the Kalman filter improved the alignment of the dynamic series. The use of gradients of average images for registration did not produce any significant improvement in the registration except in a few patient studies with low original CC values. Filtering and registration of DCE-MR images were accomplished using simple image processing techniques.