Robust Eigen-Filter Design for Ultrasound Flow Imaging Using a Multivariate Clustering Technique

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Background, Motivation and Objective

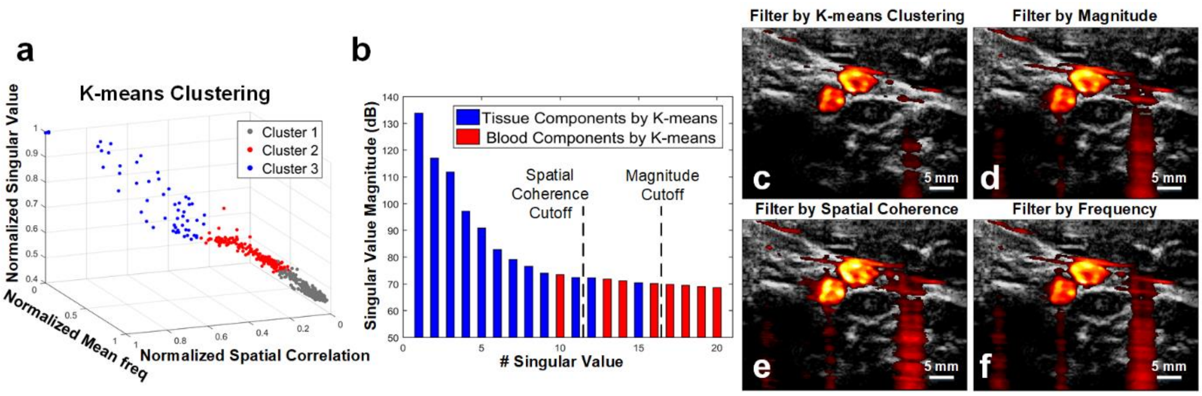
Although eigen-based filters have demonstrated vast potential in improving clutter suppression, their performance rely on proper selection of clutter eigen-components. Typically, an eigen-rank cutoff is determined as the boundary between tissue and blood flow subspaces based on the components' power, spatial or temporal features. Filter performance suffers if clutter and flow subspaces overlap after the eigen components are projected to a linear feature space for rank selection. We hypothesize that multivariate clustering based on power and spatiotemporal features of each eigen component can more effectively identify and reject non-blood eigen components.

Statement of Contribution/Methods

K-means clustering was applied to classify eigen components to clutter, blood and noise subgroups. First, singular value decomposition was performed on a 2D space-time Casorati matrix formulated from an image frame's slow-time ensembles. Next, spatial correlation and mean Doppler frequencies were derived from the respective singular vectors; along with the singular value magnitudes, these features were supplemented for clustering. Clutter filtering was achieved by rejecting components identified in non-blood clusters. To evaluate the proposed method, plane wave data at a subject's carotid were acquired using a US4US scanner with a SL1543 array (5 MHz freq; 3 kHz PRF; Tx°: 10°). Flow detection performance was assessed using receiver operating characteristic (ROC) analysis and compared with magnitude, frequency and spatial coherence rank selection methods (T-MI, 2018; 37: 1574-1586).

Results/Discussion

Eigen components were clustered into three groups (Fig. a); their corresponding subspaces were identified based on their distinctive features. In comparison to methods operating on a rigid eigen-rank cutoff, the clustering method is more adaptive in blood component selection (Fig. b). By applying our clustering strategy to remove non-blood components, the resultant power Doppler image had less spurious artifacts (Fig. c) yielding the highest area under the ROC curve (AUC:0.965), compared to thresholding by magnitude (Fig. d), spatial coherence (Fig. e) and frequency (Fig. f). Overall, multivariate clustering improved the robustness of eigen filtering by considering multiple signal features to enhance flow detection performance.



(a) K-means clustering performed on the 3D distribution of slow-time signal features acquired from in-vivo carotid region data.
(b) Singular value cut-offs (dashed lines) corresponding to clutter computed by Spatial Coherence and Magnitude based rank selection methods. Blood components (red bars) and clutter components (blue bars) identified by the K-means clustering based filter.
(c)-(f) Post-filtered power Doppler maps of different filtering methods overlaid on the carotid region B-mode image. All Doppler power maps are kept at the same dynamic range (30 dB)