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A Robust Vector Flow Estimator using Hybridized Vector Doppler and Speckle Tracking

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Background, Motivation and Objective

Accurate estimation of flow vectors, each of which comprises two components (magnitude and direction), is critical to achieve consistent flow visualization. However, it remains non-trivial to accurately track flow vectors with high spatiotemporal variations. In particular, due to limited slow-time sampling rate, Doppler-based flow vector estimators suffer from aliasing error and inherent underestimation. To overcome these issues, here we report the design of a hybrid flow vector estimator that exploits: 1) an extended least-square formulation to derive flow angles; and 2) a speckle tracking algorithm to mitigate speed underestimation.

Statement of Contribution/Methods

Our framework first estimated several flow angle candidates based on the extended least-square vector Doppler (ELS-VD) formulation (T-UFFC, 2016; 63: 1745-57) with a regularization term based on a temporal derivative to penalize outlying candidates. These initial velocity estimates were then supplemented to directional cross-correlation (T-UFFC 2003; 50: 857-72) to correct magnitude bias. This framework was implemented on a SonixTouch scanner with a L14-5 array transmitting plane waves (Tx°: -10°, 0°, 10°; 3-cycle 5 MHz pulse) at 10 kHz PRF. Its performance was tested on a spiral phantom (3 mL/s constant flow rate). Under these conditions, flow speed exceeded the Nyquist limit and aliasing was observed in the Doppler measurements. Performance was also compared with ELS-VD and a reference computational fluid dynamics (CFD) model.

Results/Discussion

The framework generally achieved accurate flow vector estimation and provided consistent rendering of flow vectors along the spiraling lumen (see Fig. 1a). The cross-lumen flow profiles marked with blue line (parallel to transducer surface) and green line (along beam direction) in Fig. 1a were plotted in Fig. 1b & 1c. Our estimation framework was able to reproduce the expected skewed flow profiles. More importantly, compared to ELS-VD, our estimator yielded lower standard deviation (1.21 cm/s vs 2.29 cm/s) and bias with respect to the CFD model (-0.86 cm/s vs -4.1 cm/s) in the lateral direction. Overall, our robust flow estimator has the potential to facilitate reliable derivation of hemodynamic parameters such as wall shear rate, especially in imaging scenarios with complex flow patterns.

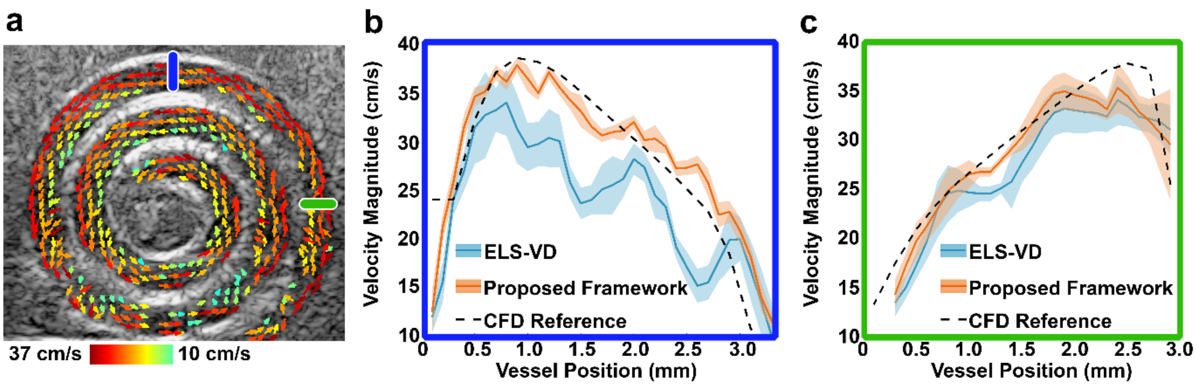

Fig. 1. Results showing improved standard deviation and bias of the framework in the spiral phantom. **a)** The vector flow profile on the spiral phantom. **b)** Plot of the mean and standard deviation of flow magnitude on the blue line of the proposed framework across 100 measurements relative to ELS-VD and CFD simulation. **c)** Plot of the mean and standard deviation of flow magnitude on the green line of the proposed framework across 100 measurements relative to traditional ELS-VD and CFD Simulation .