In vitro validation of ultrasound VFI regularization through rapid data assimilation

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Background, Motivation and Objective

Ultrasound vector flow imaging (VFI) has shown promise for measuring the true intracardiac flow patterns, but is hampered by measurement variance and dropouts. We previously proposed an efficient B-spline reconstruction framework with physical constraints based on the Navier-Stokes equations. We here improve upon the proposed method, and provide in vitro validation using optical particle image velocimetry (PIV).

Statement of Contribution/Methods

The regularization framework was improved upon with a latent variable pressure model to improve accuracy through a weakly compressible analysis scheme and periodicity in the temporal axis enabled fusion of multiple cycles. Further, 4D performance was quadrupled by switching to a fixed grid analysis enabling computation of regularization terms through efficient separable kernel convolutions.

A quasi-2D tissue mimicking phantom (PVA) of the left ventricle with ascending aorta was developed, compatible with both ultrasound (US) imaging and PIV. Pulsatile flow was imposed and synced to both imaging systems. 2D and 4D VFI data was acquired using the GE 6S and 4V probes on a GE Vivid E95 system.

Results/Discussion

In vitro validation revealed good agreement between the regularized US VFI and PIV approaches. Overall, a mild Gaussian smoother could retain peak velocities better but then struggles with low velocities and high variance, in contrast to the data assimilator. However, due to the denoising effect achieved by imposing the physical models, we see improved vorticity estimates throughout the whole pump cycle. Additionally, the optimized formulation explored here resulted in optimization runs in the range of 120 and 180 seconds for 3D and 4D respectively. In view of this, the established framework plausibly provides a method for bedside reconstruction and regularization of ultrasound vector flow imaging, needed for a full characterization of intraventricular flow patterns.

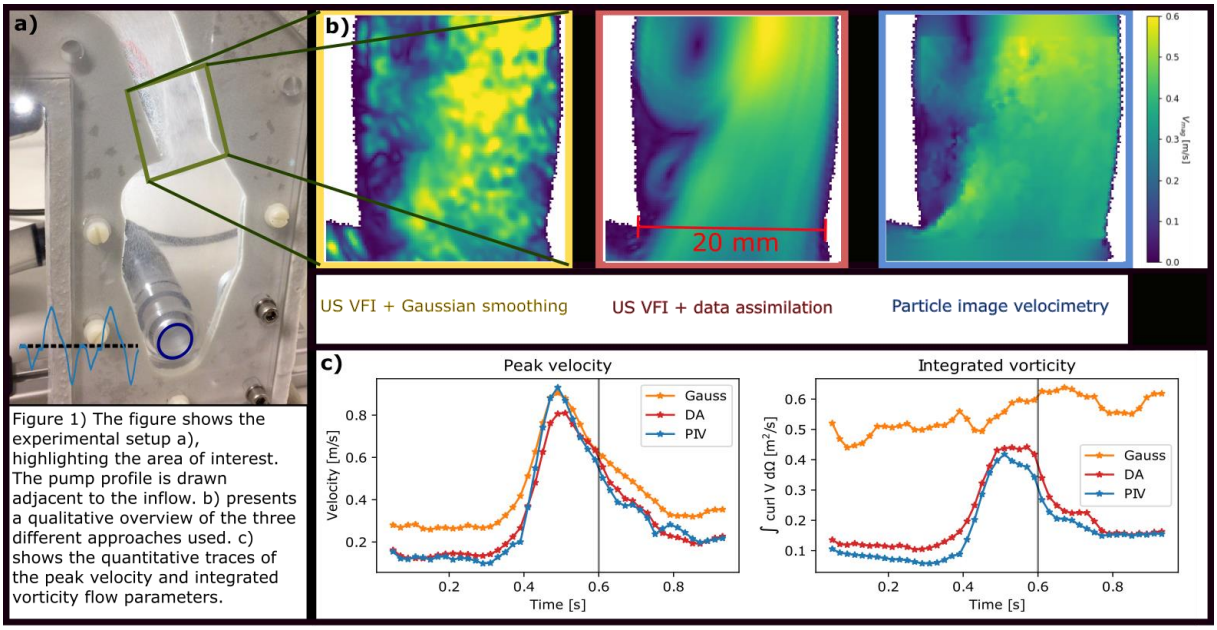

Figure 1) The figure shows the experimental setup a), highlighting the area of interest. The pump profile is drawn adjacent to the inflow. b) presents a qualitative overview of the three different approaches used. c) shows the quantitative traces of the peak velocity and integrated vorticity flow parameters.