Spatial Up-sampling of Synthetic PIV Data using Frequency-domain Physics Informed Neural Networks

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Motivation: Experimental measurements of fluid flows are often sparse, made up of velocity or pressure measurements taken at discrete spatial locations with gaps between them. This spatial sparsity limits the accuracy of techniques that seek to infer unsteady forces, energy transfer, or distill dynamical models from flow data. Sparse datasets drawn from fully nonlinear CFD can be significantly up-sampled [1]; however, up-sampling real flow physics requires correcting systematic and random measurement errors. This study will investigate how a Fourier-averaged Navier-Stokes (FANS) based physics-informed neural network (PINN) up-sampling method performs when faced with these errors resulting from the particle image velocimetry (PIV) process.

Methods: To produce the ground truth dataset for this work, fully nonlinear CFD simulations for a circular cylinder in cross flow at $Re_D = 150$ were performed using OpenFOAM, following [2]. The velocity field is approximated in time using a set of 8 Fourier modes, with an L^2 truncation error below 0.01%. Particle velocities are interpolated by tessellating the CFD mesh, identifying the relevant element using a k-D tree, and interpolating using the k-nearest neighbor method. Massless PIV particles were stepped through time and space using the 4th-order Runge-Kutta method, with a time step of 10^{-3}. Particles were modeled in the synthetic images as Gaussian functions in space. Vector fields were computed using Lavision DaVis 11.2 with final window sizes from 16×16 to 64×64 to investigate the averaging effect of PIV window size.

Results and Next Steps: An example vorticity field from the synthetic PIV data with a window size of 32×32 and its difference relative to the DNS vorticity are shown in Figure 1. Uncorrelated noise is added to the synthetic PIV vector fields, and up-sampling will be performed using data assimilation, following [1]. The up-sampling error for different noise levels will be evaluated by comparison with the underlying DNS dataset.

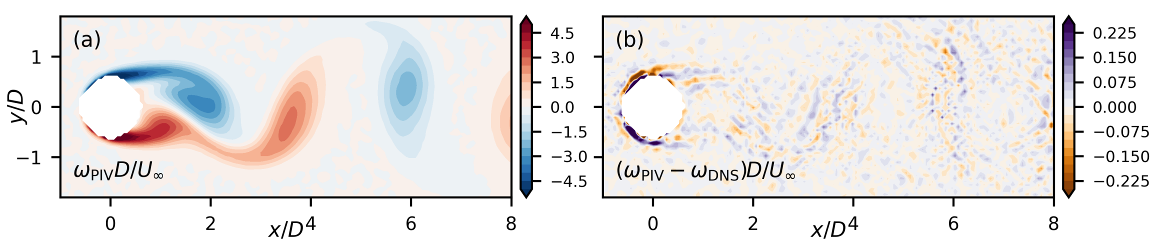

Figure 1: (a) Instantaneous vorticity contour from synthetic PIV, (b) difference from DNS vorticity.

References

[1] C. M. O'Neill, "Frequency-domain data assimilation of periodic flow using physics-informed neural networks", Master's thesis, University of Calgary, 2025.

[2] M. Hassanpour, C. Morton, and R. J. Martinuzzi, "Effect of harmonic inflow perturbation on the wake vortex dynamics of a cylinder undergoing two-degree-of-freedom vortex-induced vibration near a plane boundary," *Physics of Fluids*, vol. 34, no. 10, 2022

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