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RECONSTRUCTION OF FLOW FIELDS FROM DATA USING PHYSICS-INFORMED GAUSSIAN PROCESS REGRESSION

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ABSTRACT

Recently, there is a growing interest in adapting data assimilation methods to fluid flow frameworks. Data obtained from particle tracking velocimetry (PTV) enables modelling in a Lagrangian context, which motivates the development of corresponding techniques and resources [1]. In parallel, Gaussian process regression (GPR) has been adapted to approximate solutions of partial differential equations (PDE) by using kernel representation formulas [2], allowing uncertainty quantification (UQ). A reconstruction approach of flow fields based on a Lagrangian simulation of a viscous flow over a periodic domain was presented by [3]. We propose a reconstruction approach to simulate 2D incompressible flows in a tunnel setting with an obstacle (e.g. cylinder or airfoil profile), by considering estimation from a physics-informed curve-constrained Gaussian process (Fig. 1).

Considering PTV flow data obtained from high-precision external simulations, with \mathbf{V} , the velocity values on trajectories \mathbf{Y} , inlet and exit boundary conditions on velocity $\tilde{\mathbf{V}}$ over N_{bd} domain boundary points $\tilde{\mathbf{X}}$, and physical constraints around an obstacle, we study a hybrid reconstruction approach that combines data and a numerical method on the vorticity system over collocation trajectories \mathbf{Q} with vorticity values \mathbf{W} . Estimation of velocity will be of the form $\mathbf{u}^*(\mathbf{x}, t) = \mathbb{E}(\mathbf{Z}(\mathbf{x}) | \mathbf{Z}(\mathbf{Y}(t)) = \mathbf{V}(t), \mathbf{Z}(\tilde{\mathbf{X}}) = \tilde{\mathbf{V}}, \text{curl } \mathbf{Z}(\mathbf{Q}(t)) = \mathbf{W}(t))$, for $(\mathbf{x}, t) \in \Omega \times [0, T]$, where \mathbf{Z} is a vector-valued centered Gaussian process indexed in Ω with a physics-informed matrix-valued kernel \mathbf{K} satisfying a divergence-free condition and continuous-type boundary conditions on the obstacle. Further collocation sub-sampling techniques are being studied to enhance the performance of the estimation at each time step, as well as kernel parameters identification by maximum likelihood estimation (MLE).

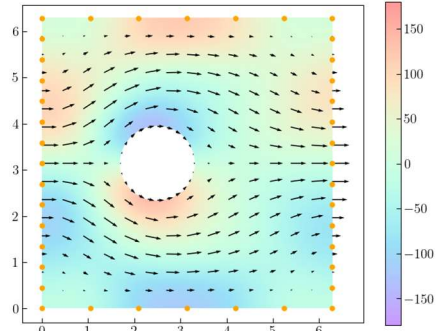


Fig. 1 : Velocity field and vorticity (colormap) reconstruction from GPR using an obstacle-constrained physics-informed kernel and $N_{bd} = 40$ domain boundary condition points (orange). No discrete condition points are used in the obstacle boundary.

REFERENCES

- [1] B. Leclaire, P. Cornic, F. Champagnat, E. Fabre, and F. Calmels. A web portal for automatic performance evaluation of lagrangian particle tracking and data assimilation algorithms. In *20th International Symposium on the Application of Laser and Imaging Techniques to Fluid Mechanics*, Lisbon, Portugal, 2022.
- [2] Y. Chen, B. Hosseini, H. Owhadi, and A.M. Stuart. Solving and learning nonlinear PDEs with Gaussian processes. *J. Comput. Phys.*, 447:110668, 2021.
- [3] H. Owhadi. Gaussian process hydrodynamics. *App. Math. and Mech.*, 44(7):1175–1198, 2023.