Artificial Intelligence meets complex flows, from optimal navigation to reconstruction of turbulent data

Michele Buzzicotti

Department of Physics & INFN, University of Rome Tor Vergata, Via della Ricerca Scientifica 1, 00133 Rome, Italy

ABSTRACT

We study the applicability of artificial intelligence (AI) tools to different open problems in fluid dynamics, from the search of an optimal navigation strategy in complex environments to data reconstruction from partial measurements of turbulent flows. To solve the navigation problems we follow the Reinforcement Learning (RL) approach. Here, we focus on finding the path that minimizes the navigation time between two given points in a fluid flow, known as the Zermelo's problem. In particular, we consider the case of a vessel navigating in a 2d turbulent sea, which has a slip velocity with fixed intensity but variable direction [1]. In the ideal case of time-independent flow, where an analytical solution can be found, we show that RL solutions converge to the analytical optimal strategies. Furthermore, we show how the RL approach is able to take advantage of the flow properties in order to reach its target also in more complex/real scenarios, being robust with respect to small changes in the initial conditions and to external noise. These results illustrate the potential of RL algorithms to model adaptive behavior in complex flows and pave the way towards the engineering of smart unmanned autonomous vehicles that solve difficult navigation problems. The search for an optimal navigation strategy is key in several applications, with a potential breakthrough in the open challenge of Lagrangian data assimilation (DA), crucial for both meteorology and climate modeling. In the DA direction, we also explore the capability of Generative Adversarial Network (GAN) to generate missing data in turbulence. In particular, we investigate on a quantitative basis, their use in reconstructing 2d damaged snapshots extracted from a large database of numerical configurations of 3d turbulence in the presence of rotation, a case with multi-scale random features where both large-scale organized structures and small-scale highly intermittent and non-Gaussian fluctuations are present [2]. Following a reverse engineering approach, we also aim to investigate which features of the input flow data are required in order to obtain a better full-field reconstruction. Finally, the TURB-Rot database, http://smart-turb.roma2.infn.it of roughly 300K 2d turbulent images is presented and download details are released [3].

References

[1] Biferale, L., Bonaccorso, F., Buzzicotti, M., Di Leoni, P. C., & Gustavsson, K. (2019). Zermelo's problem: Optimal point-to-point navigation in 2D turbulent flows using Reinforcement Learning. Chaos: An Interdisciplinary Journal of Nonlinear Science 29.10 (2019): 103138.

[2] Buzzicotti, M., Bonaccorso, F., Di Leoni, P. C., & Biferale, L. (2020). Reconstruction of turbulent data with deep generative models for semantic inpainting from TURB-Rot database. arXiv preprint arXiv:2006.09179.

[3] Biferale, L., Bonaccorso, F., Buzzicotti, M. and di Leoni, P.C., 2020. TURB-Rot. A large database of 3d and 2d snapshots from turbulent rotating flows. arXiv preprint arXiv:2006.07469.