Development of a novel coherent structure analysis tool for wall-bounded turbulence based on machine-learning algorithms

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1 Background

Ever-growing computational power and the research community's eager for ever-larger fluid simulations lead to a production of overwhelming amount of data everyday. Therefore, it is no exception in the field of fundamental turbulence research that the era of Big Data is here [1]. As a result, the availability of high-resolution DNS data is no longer the bottleneck of our research activities, however the state-of-the-art hardware and software infrastructure, as well as the skill required to handle such large-scale scientific data have become the main differentiator in our research outcome. In other words, being able to produce DNS data and performing "standard" set of statistical analysis can no longer be sufficient to be competitive in this research field, but the ability to perform innovative analysis that is only possible with high-quality large-scale data is.

The state of the flow of our interest is called "turbulence", and it is believe to be impossible to determine the precise dynamics *a-priori* because of the nonlinear/chaotic nature. It is however known to be possible to explain the key statistical properties reasonably well by analysing the dynamics of the self-organised patterns (e.g. vortices, layers, jets) that emerges in turbulence and carry significant amount of energy. Such self-organised patterns are often referred to as coherent structures, which undergo constant topological morphing and interactions with other surrounding structures, for instance splitting and merging.

Although focusing on the coherent structures reduces the degree of freedom of our analysis, the complex, multidimensional, multi-scale natures of turbulent fluid motions still very often exceed our capability of recognition. Fortunately, however, tools to analyse such large-scale and complex data have been rapidly become available recently in the field of machine-learning. Therefore, our aim of this project is to perform preliminary study of coherent structure analysis based on the machine-learning algorithms.

2 Planned tasks

The implemented tool should be able to:

1. receive list of geometrical and physical quantities of interests;
2. receive an instruction to perform either: linear regression, nonlinear regression or classification;
3. save the outcome in a reusable data format (e.g. HDF5);
4. display and save the outcome graphically (e.g. EPS-format).

As the initial attempt, some simple machine-learning algorithms such as SVR/SVM are expected to be employed. Following the implementation, the tool should be applied to turbulent flow fields with special focus on validation as follows:

1. extract coherent structures from canonical turbulence dataset based on selected criteria (e.g. λ_2-/Q-criterion, ω, self-similar vortex cluster of [2]);
2. compute and store physical volume-averaged quantities associated with the educed structures, such as turbulent kinetic energy (TKE), TKE production, TKE dissipation, and Reynolds stresses and the corresponding isotropy;
3. compute geometrical features associated with the educed structures, such as characteristic length-scale, aspect ratios, curvature, fractal dimension, orientation with respect to the closest wall, wall-distance and if the structure is attached to wall or not;
4. save the data;
5. based on the computed geometrical and physical features, perform coherent structure analysis on the educed structures;
6. validate the results against the existing feature-based coherent structure studies (for isotropic turbulence, [3]; plane channel flow, [4]);
7. (optional) explore the new relations between the geometrical and physical features that have not been discussed before.

Required skills

- basic knowledge in UNIX/Linux system
- strong interest in fundamental fluid dynamics
- sufficient experience in scripting languages (e.g. MATLAB, Python, R)
- sufficient communication skill in English

Recommended skills

- basic knowledge in machine-learning algorithms

Benefits for applicant

- practical experience in high-performance computing
- practical experience in CFD
- in-depth supervision in scientific computing and turbulence research
- (ideal preparation for Master's thesis)

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