Stage de Master EFEMO
2019-2020, durée 5 mois

Sujet : Generating synthetic turbulent flows using Machine Learning

Encadrant(s) : Fx Demoulin B Duret

Mots clés (4) : "Turbulence" "Simulation" "Deep Learning" "Machine Learning"

Objectifs : (mini 20 lignes, maxi 40 lignes)

Machine learning has witnessed major advancements and developments in the last decade. For machine learning and neural network applications have proven their major validity in multiple fields namely health, transportation, industry …

In mechanical engineering, computational fluid dynamics (CFD) is a major field of research today that enables researchers to solve problems and simulate certain setups related to thermo-fluid applications. However, one essential obstacle that halts any major breakthrough in the field is the expensive cost that CFD simulations cost, whether from the computational power required to complete the simplest analysis or the time it takes to solve problems such as multi-phase flows, or turbulent flows in 3D.

One thing that should be mentioned is that every CFD simulation generates a huge amount of data, and here is where the machine learning part plays its role. In fact, because of the big amount of data generated, deep neural networks could be compiled base on these data to make predictions in the field of CFD. This approach is promising, especially when it comes to the reduction of time needed to complete simulations. This of course is expected to reduce accuracy, but this is a problem that can be researched and improved on its own.

The objective of this master internship is to research on a particular application of CFD in machine learning, namely investigation the modeling of a synthetic, single phase, turbulent flow.

We will first start by using Langevin's equations and one hand to generate data and using machine learning on the other hand to finally compare both kind of results. In fact, modeling of turbulence signal using Langevin's equations is well-known problem, and the main work will be mainly related to model the case using machine learning and to evaluate the results.

The neural network created can be further enriched by not only using the data from Langevin equation but also by using more advance model or experimental data and direct numerical simulations. This progressive way to introduce more and more realistic physics and to monitor how the network is able to adapt itself will be very instructive on further possibility of using deep learning in physics and more particularly in fluid mechanics.

Résultats attendus pour la rédaction du rapport de stage :

This internship report should contain firs a bibliographic review on synthetic turbulent signal together with a description of the characteristic of a turbulent signal.

Simple network algorithms for regression and generative process will be studied.

Using python script, tensor flow and keras libraries generative neural network (NT) will be built and reported based on example from literature.

Starting form data issued of Langevin equation, the learning process of NT will be achieved and evaluated with respect to the dedicated convergence criteria.

Depending of the result, more advanced model to generate turbulence signal (including possibility DNS data or experimental result) will be used on the same NT architecture to determine its ability to included new turbulent feature.
A possible extension of research to go beyond these tasks is to include this generated turbulent signal as an inlet condition of a classical CFD configuration based on OpenFoam to test their real benefit in term of application.

Work Program :
Month 1: Bibliographic Study
Month 2: To learn Python script to solve Langevin Equation and extract "pseudo turbulent" signal main characteristics
Month 3: To use and practice already implemented deep learning networks
Month 4: To implement and test a new network architecture proposed by Fukami et al. 2019
Month 5: Master thesis report

Moyens utilisés : (*Préciser : les moyens que vous souhaitez utiliser et leur disponibilité ou non au sein de votre équipe. Si vous allez faire appel aux services communs (atelier, électronique, info etc…) préciser le type de demande.*

This work is part of deep learning initiative at CORIA thus the support of Alexandre Poux to help on the numeric and to coordinate exchange within the CORIA is expected.

Computer resources can be claimed if necessary to CRIAN, direct GPU on PC can be used also, but direct way is to used Google Colab platform that is sufficient for the time being.

Travaux Développés sur le sujet au laboratoire (Master, Thèse, …)
Hichem MEDJADBA: Bachelor intership in 2019 (2 months) : Test of Langevin equation with python, first neural network tested.
Georgio Fadi Daloul El Sayegh, short term intership Master 1 level (3 months): Visit of a master student from Libanon, testing 2D synthetic turbulent signal, first Deep Convolutional Generative Adversarial Network used for this application.

Références bibliographiques de l'équipe en rapport avec le sujet :

Références bibliographiques :

- Kutz, J. N. (2017). Deep learning in fluid dynamics. Journal of Fluid Mechanics, 814, 1-4. doi:10.1017/jfm.2016.803
- Hanna, Botros & Dinh, Nam & Bolotnov, Igor. (2018). Coarse Grid Computational Fluid Dynamics (CG-CFD) Error Prediction via Random Forest Regression.
- Guo, X., Li, W., & Iorio, F. (2016). Convolutional Neural Networks for Steady Flow Approximation. Proceedings of the 22nd ACM SIGKDD International Conference on Knowledge Discovery and Data Mining - KDD 16. doi:10.1145/2939672.2939738
- K. Fukami, Y. Nabae, K. Kawai, and K. Fukagata, 'Synthetic turbulent inflow generator using machine learning', *Phys. Rev. Fluids*, vol. 4, no. 6, p. 064603, Jun. 2019.