Multiscale Modal Analysis of Experimental and Numerical Data

Experiments in Fluid Mechanics, Warsaw, 23-24 October 2017

Miguel Alfonso Mendez

Many systems in engineering and applied sciences are governed by multiscale, nonlinear dynamical processes. While the evolution of numerical and experimental tools allows for datasets with ever-growing spatial and temporal resolutions, data processing algorithms must be able to extract the relevant dynamics from large and high-dimensional datasets. This distillation process is the purpose of data-driven model order reduction (MOR), which lays the foundations of modern data compression, filtering, pattern recognition and machine learning, and which is nowadays becoming a necessary toolbox for the fluid dynamics community.

The scope of this presentation is twofold and it is divided into two parts accordingly. The first part of the presentation gives an overview of the common MOR techniques used in fluid dynamics, namely the Discrete Fourier Transform (DFT), the Discrete Wavelet Transform (DWT), the Proper Orthogonal Decomposition (POD), and the Dynamic Mode Decomposition (DMD). The formulation of method is proposed in terms of a projection onto a suitable set of basis elements (modes), which has its own limitations and strengths, highlighted via a set of simple synthetic test cases.

The second part of the presentation reports on the developments of a new decomposition, referred to as Multiscale Proper Orthogonal Decomposition (mPOD), which combines the energy optimality of the POD, the limited frequency bandwidth of the DFT/DMD, and the multi-scale and time-frequency localization capabilities of the DWT. The mPOD uses Multi-Resolution Analysis (MRA) on the correlation matrix of the dataset to produce a set of PODs at multiple scales, reassembled via standard re-orthogonalization methods. After proving the superior feature extraction capabilities of the mPOD on the proposed synthetic test cases, the new decomposition is tested on an experimental and a numerical dataset. The first consists of Time-Resolved Particle Image Velocimetry (TR-PIV) of an oscillating gas jet impinging on a deformable interface; the second consists of a Finite Difference simulation of a nonlinear advection-diffusion problem, derived from the vorticity-streamline formulation of the 2D incompressible Navier-Stokes equations.