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PROPOSITION DE POST-DOCTORAT

Intitulé : Joint optimization of actuator/sensor/compensator for closed-loop control of fluid flows

Référence : **PDOC-DAAA-2025-001**
(à rappeler dans toute correspondance)

Début du contrat : à partir de 01/2025

Date limite de candidature : 05/2025

Durée : 18 mois - Salaire brut : environ 38 k€ annuel (assurance médicale incluse)

Mots clés

Closed-loop flow control, non-smooth non-convex optimization

Profil et compétences recherchées

PhD in fluid mechanics, control science or applied mathematics

Présentation du projet post-doctoral, contexte et objectif

With ever-increasing constraints on the environmental impact of aviation, active flow control appears as a key enabling technology. Closed-loop control may be used to reduce jet noise emission, skin-friction drag or avoid flow separation for instance. Designing optimal closed-loop setups is a challenging task because of the high-dimesionality of fluid systems. Indeed, state-of-the-art methods for controller synthesis (optimal H_2 or robust H_∞) cannot easily manage systems of order greater than O(100). As a result, the most common approach is to first form a reduced-order model (ROM) of the flow, optimally capturing its input-output behaviour [1]. The ROM is associated with an arbitrarily chosen set of actuators and sensors, inevitably resulting in suboptimal control setups. Ideally, we would like to jointly optimize the actuators, the sensors and the compensator [2], but achieving this goal in high-dimension requires a new methodology.

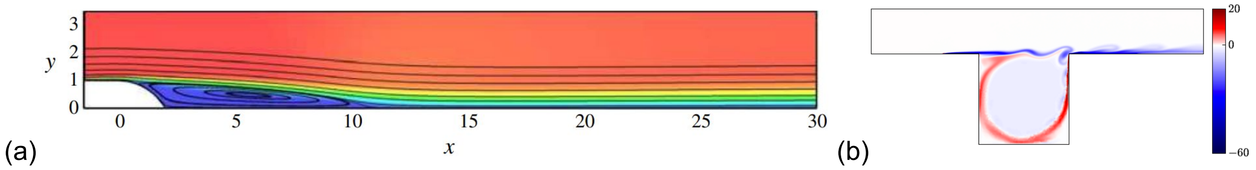

Figure 1: Canonical benchmark cases for the co-design problem : (a) noise-amplifier flow (backward facing step [6]) and (b) oscillator flow (open-cavity [7]).

In this postdoc, we wish to explore novel approaches to solve the co-design problem. We aim to work directly with the full-order model, or resolvent operator, connecting all possible inputs to all possible outputs. The key idea is that the performance index that we seek to optimize, for instance the H_2 or the H_∞ norm of the closed-loop resolvent operator, is related to eigenvalues of large-scale sparse matrices. Therefore, Krylov subspace techniques may be used to efficiently evaluate the objective functional. Similarly, the gradients of the functional with respect to the free parameters (of the actuators/sensors/compensator) may be quickly computed [3]. In essence, Krylov subspace techniques may be used to perform model reduction on-the-fly, during the optimization procedure, without preselecting any actuator or sensor. The optimization problem is however non-convex, and also non-smooth because a) the greatest eigenvalue is not always the same when free parameters are varied, b) closed-loop stability must be enforced. However, this class of problems can now be efficiently addressed using a recently developed BFGS-SQP algorithm [4]. The sparse linear algebra and eigenvalue problems will be solved using the libraries PETSc/SLEPc, while the library pyGRANSO [5] will be used for optimization.

The new approach will be investigated on two canonical 2D incompressible flows (see figure 1): the backward-facing step (a noise amplifier) and the open cavity (an oscillator) ; using the finite-element code FEniCS. Several parametrizations of the actuators and sensors will be investigated, with various constraints (sparsity, volume-force versus boundary condition). With access to the full input-output dynamics, great attention will be paid to the choice of the system norm to be optimized (H_2 / H_∞ norm [8], numerical abscissa, maximum linear transient growth [9]).

References:

[1] Sipp, D., & Schmid, P. J. (2016). Linear closed-loop control of fluid instabilities and noise-induced perturbations: a review of approaches and tools. *Applied Mechanics Reviews*, *68*(2), 020801.

[2] Chen, K. K., & Rowley, C. W. (2011). H2 optimal actuator and sensor placement in the linearised complex Ginzburg–Landau system. *Journal of Fluid Mechanics*, *681*, 241-260.

[3] Werner, S. W., Overton, M. L., & Peherstorfer, B. (2023). Multifidelity Robust Controller Design with Gradient Sampling. *SIAM Journal on Scientific Computing*, *45*(2), A933-A957.

[4] Curtis, F. E., Mitchell, T., & Overton, M. L. (2017). A BFGS-SQP method for nonsmooth, nonconvex, constrained optimization and its evaluation using relative minimization profiles. *Optimization Methods and Software*, *32*(1), 148-181.

[5] https://github.com/sun-umn/PyGRANSO

[6] Dergham, G., Sipp, D., & Robinet, J. C. (2013). Stochastic dynamics and model reduction of amplifier flows: the backward facing step flow. *Journal of Fluid Mechanics*, *719*, 406-430.

[7] Leclercq, C., Demourant, F., Poussot-Vassal, C., & Sipp, D. (2019). Linear iterative method for closed-loop control of quasiperiodic flows. *Journal of Fluid Mechanics*, *868*, 26-65.

[8] Benner, P., & Mitchell, T. (2018). Faster and more accurate computation of the H_∞ norm via optimization. *SIAM Journal on Scientific Computing*, *40*(5), A3609-A3635.

[9] Martinelli, F., Quadrio, M., McKernan, J., & Whidborne, J. F. (2011). Linear feedback control of transient energy growth and control performance limitations in subcritical plane Poiseuille flow. *Physics of Fluids*, *23*(1).

Collaborations extérieures

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