DATA-DRIVEN NONLINEAR STABILITY MAPS FOR A DELAYED-FEEDBACK PD-STABILIZED INVERTED FLAG

Giacomo Abbasciano[1], Prof. Dr. Filippo Coletti[1], Prof. Dr. George Haller[1]
[1] *Department of Mechanical and Process Engineering, ETH Zurich, 8092 Zurich, Switzerland*

Introduction

In [1], water-tunnel video recordings were used to develop a two-dimensional reduced-order model (ROM) that captures the highly nonlinear flapping behavior of an inverted flag in uniform flow. This model reduces the infinite-dimensional dynamics onto a two-dimensional spectral submanifold (SSM) originating from the two slowest modes of the saddle equilibrium. While experiments reveal a saddle fixed point and a limit cycle, the SSM-based model also identifies two additional symmetrical unstable fixed points reported in prior studies. This method reconstructs system dynamics using only a few freely decaying trajectories, requiring no additional system information.

This project aims to stabilize the inverted flag's two unstable fixed points in the flapping regime through proportional-derivative (PD) control with time-delayed feedback. Predicting stability maps for such dynamical systems is essential for control (see [2]). A data-driven approach using parametric SSM reduction is employed to construct a nonlinear stability map. By identifying the two-dimensional SSM from videos for a few points in the controller gain space, we develop a parametric ROM for the linearization that captures the location of the bifurcation surfaces. The resulting stability map, derived from a few experimental time series of a scalar observable at a few points in the parameter space, effectively characterizes the stability boundaries of the infinite-dimensional, time-delayed PD-controlled system (see Figure 1).

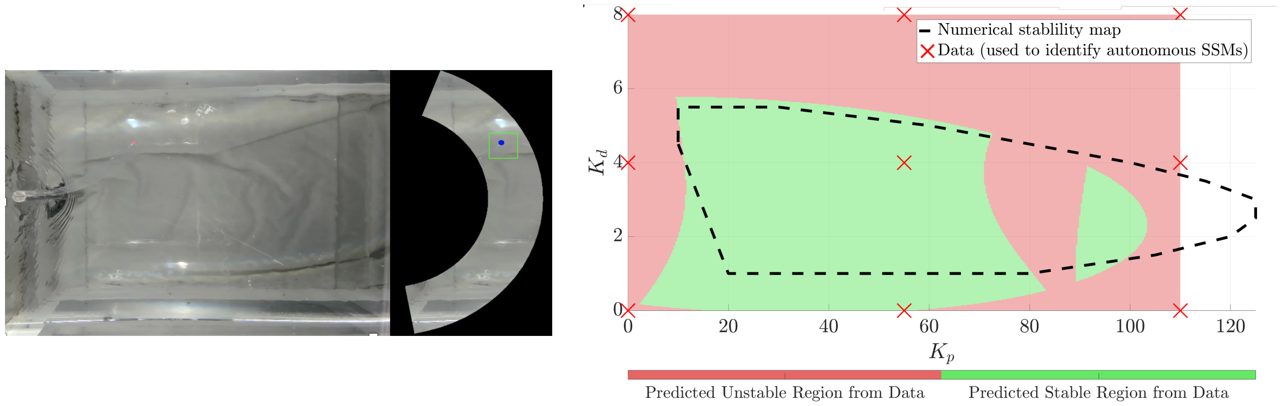

FIGURE 1. *Left: Water tunnel and image analysis. Right: Data-driven stability map for an underactuated, two-degree-of-freedom nonlinear mechanical system with delayed feedback.*

Goals

- Collect time series of scalar observables from videos at different points in the gain space of the controller to identify SSM-reduced dynamics for the two symmetrical fixed points of the system.
- If time permits, extend the study to the undeformed equilibrium position.

Requirements

- Relevant coursework or hands-on experience in control and image analysis.
- Prior experience in experimental fluid dynamics is a plus.

Application Process

Submit your CV and transcripts (BSc, MSc) to `gabbasciano@ethz.ch`. This project is intended as a BSc Thesis/Semester Project in Experimental Fluid Dynamics and Flow Control, with different scopes.

References

[1] Zhenwei Xu, Bálint Kaszás, Mattia Cenedese, Giovanni Berti, Filippo Coletti, and George Haller. Data-driven modelling of the regular and chaotic dynamics of an inverted flag from experiments. *Journal of Fluid Mechanics*, 987, 5 2024.

[2] Mate B. Vizi and Gabor Stepan. Digital stability of the furuta pendulum based on angle detection. *JVC/Journal of Vibration and Control*, 30:588–597, 2 2024.