Ph. D. Thesis in Automatic Control

Title: Estimation and control of flexible structures with physics informed learning

Supervisors

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Context/Aim

This thesis will mainly take place within the ROMOCO team at AS2M (Automatique et Systèmes Micro-Mécatroniques) department of FEMTO-ST Besançon. The aim of this thesis is to develop identification, estimation and control methods for flexible structures (1D and 2D) actuated by HASEL actuators, combining artificial intelligence (AI) techniques and the port Hamiltonian framework.

Key words

Port Hamiltonian systems; HASEL Actuator; Flexible structure; PINN

Detailed description

This thesis aims to address the estimation and control problem of HASEL actuator driven flexible structures (1D and 2D)(experimental set-up in 1D case existing in Department AS2M of FEMTO-ST institute as shown in Figure 1) using the port Hamiltonian structure informed Neural network.

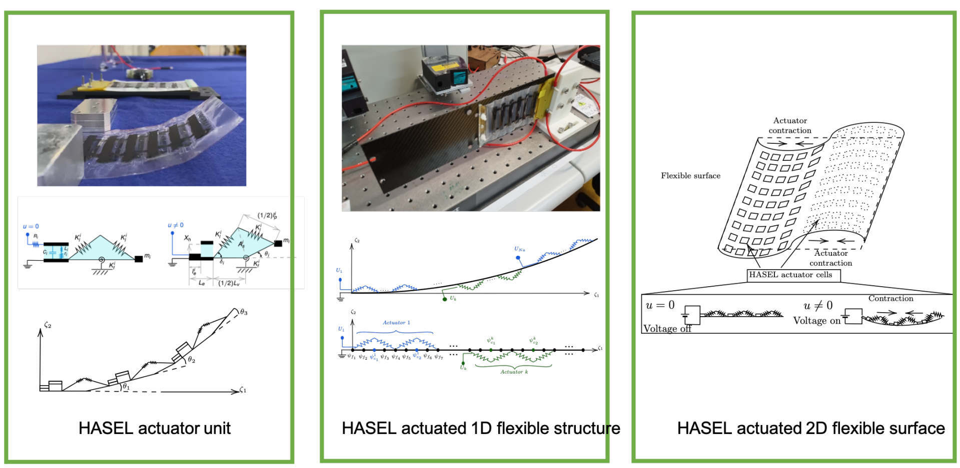

Figure 1: Left. HASEL actuator; Middle. HASEL driven 1D flexible structure; Right. HASEL driven 2D flexible structure

In recent years, soft robots have provided greater safety for humans and the ability to easily handle fragile objects, thanks to their flexible structure, compared to traditional rigid robots. Their adaptability allows them to operate in challenging environments. Inspired by natural movement, they move more fluidly while being lightweight and less cumbersome. HASEL actuators combine the flexibility of materials with the ability to generate significant forces while remaining lightweight, fast, and capable of self-repair, making them promising for applications in soft robotics [1]. Modeling and controlling HASEL actuators is challenging due to their nonlinear behavior, the complex interactions between electrostatics and fluid mechanics, and their high flexibility, which makes their dynamics difficult to predict and control precisely [2].

Considering the multi-physical character of the mechanical structure actuated by the electric-active HASEL actuator and their nonlinear characteristics and power conserving interconnection relation, of sub-systems, the modeling of such kind of system is quite challenge. The port Hamiltonian (PH) formalism is particularly well-adapted for the modeling and the control of multi physical systems, such as structural mechanical systems [3], electro-mechanical systems [4], etc. The PH approach is based on the principle of conservation of energy and provides a clear physical interpretation of control design strategies. Due to these properties, this approach is particularly suitable for modeling and controlling flexible structures powered by HASEL actuators.

On the other hand, due to the manufacturing technology and the assumptions used in modeling HASEL actuators, as well as the limitations in measuring actuated flexible structures, conventional control laws lack the precision needed to control this type of system. This thesis proposes developing and investigating the contribution of data-driven algorithms, with neural networks guided by physical constraints, to enhance the performance of estimation and control of a flexible surface with HASEL actuators. This will improve robustness against uncertainties introduced in the modeling process when compared to real-world applications.

This thesis proposes combining data-driven approaches (neural networks) with physical and energy-based methods, particularly the port-Hamiltonian approach, to develop artificial intelligence (AI) methods that integrate physical principles. The approach involves leveraging the physical knowledge of the system to propose a model based on the interconnection of the flexible structure, described by partial differential equations (PDEs), and the HASEL actuators, described by ordinary differential equations (ODEs).

Subsequently, a numerical model will be obtained through a discretization method that preserves the physical structure. Within the framework of this structure-preserving numerical model, neural network based methods will be developed, utilizing limited experimental measurements to reconstruct a refined model that incorporates the system's real physical characteristics. With the reconstructed data, control laws will be applied to perform the desired tasks. The overall estimation and control strategies are illustrated by the Fig. 2.

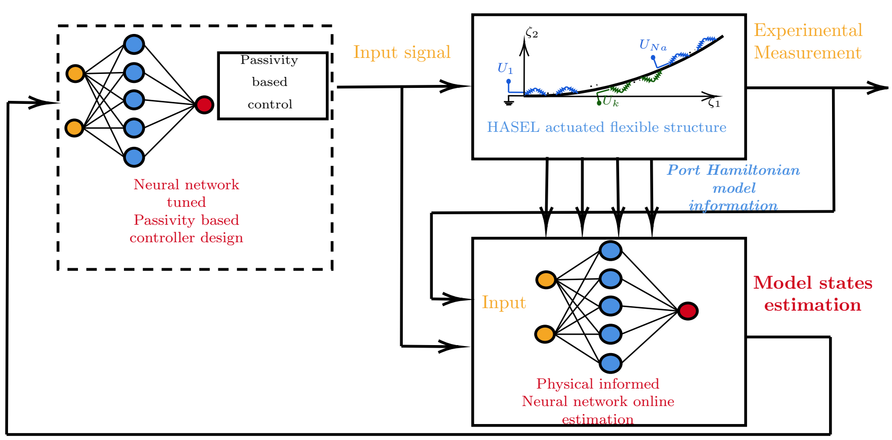

Figure 2: PINN Model Estimation and Real-Time Control of the Structure Scheme

Identification and control methods using neural networks within the framework of the port-Hamiltonian approach have been proposed in [5, 6, 7] for simple systems but lack experimental validation. This project aims to develop artificial intelligence (AI) methods by integrating the port-Hamiltonian approach for complex systems, followed by experimental validation.

Another major focus is the study of the contribution of physical priors present in bimodal data, combined with appropriately adapted uncertainty measurements, in the context of flexible structures.

Objectives and time planing

- In the first year, we plan to employ an infinite-dimensional port-Hamiltonian system to model the dynamic behavior of the flexible structure actuated by HASEL actuator as shown in the middle figure of Fig. 1. Moreover, we will attempt to employ the Neural Network method with the port Hamiltonian structure preserved discritization model to develop the estimation algorithm using the experimental input-output measurement of the setup.
- In the second year, We aim to develop the control methodology to control the shape of the flexible structure using the passivity based method with the control parameter tuned by the Neural Network based algorithm.
- In the last year, we plan to improve the experimental setup to the 2D flexible surface actuated by the HASEL actuator. Furthermore to extend the obtained methods from the prvious two years to estimate and control the 2D flexible structure.

Candidates profile

- Excellent MSc/Engineer in Automatic Control, Applied mathematics, Robotics.
- Strong knowledge background in automatic control and/or applied mathematics, experience in Artificial Intelligence.
- Fluent in speaking and reading English.

Funding and application

The Ph. D thesis may start in October 2025.

Please send your application documents, including **a detailed CV, a cover letter, all transcripts, and recommendation letters** to both advisers, Prof. Yann Le Gorrec (legorrec@femto-st.fr), Dr. Yongxin Wu (yongxin.wu@femto-st.fr).

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