Ph. D. Thesis in Automatic Control

Title: Energy based modeling and distributed control of a compliant bio-medical system

Advisors

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Context/Aim

This thesis will take place within a collaborative project between CODE (COntrol and DEsign) and MiNaRoB (Micro-/Nano-Robotique Biomédicale) teams of AS2M (Automatique et Systèmes Micro-Mécatroniques) department of FEMTO-ST Besançon. The aim of this project is to propose new models and robust control laws for a compliant bio-medical system actuated through electroactive polymers by using the port Hamiltonian framework.

Key words

Port Hamiltonian systems; Distributed parameter systems; Multiphysics modeling; Model reduction; Robust control design.

Detailed description

This thesis aims to propose efficient distributed control strategies for a compliant endoscope [1] actuated by electroactive polymers. The considered system will be first approximated by a flexible beam (Timoshenko or Euler-Bernoulli beam) connected to patches of electroactive polymers. This compliant endoscope and its simplified model are shown in Fig 1. The main objective of this thesis is to propose reliable and precise models for this complex system, and furthermore, to develop robust control laws in order to control the head and the body trajectories in the framework of non-invasive surgery applications. Motivated by the multi-physical, nonlinear and distributed aspects of this system, the port Hamiltonian formalism will be used for the modeling and the control design.

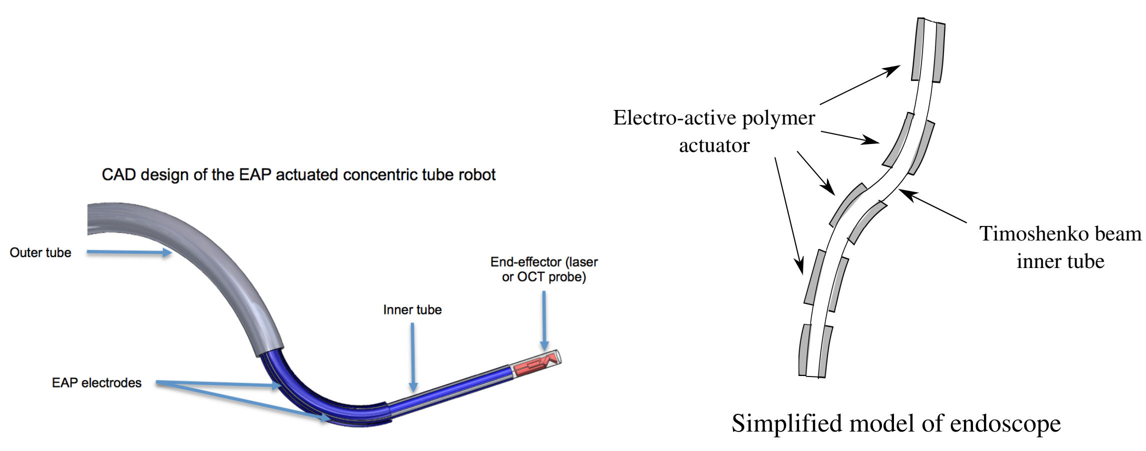

Figure 1: Electro-active polymer actuated compliant endoscope

The port Hamiltonian formalism is particularly well-adapted for the modeling and the control of non linear multi physical systems [2] such as electro-mechanical systems. It is based on the principle of conservation of energy and provides a clear physical interpretation of control design strategies. Initially proposed in the context of finite dimensional systems, the port Hamiltonian approach has been generalized to distributed parameter systems described by partial differential equations (PDEs) in [3]. A first attempt to model electroactive polymers using the port Hamiltonian framework has been proposed in [4]. It considers the multiscale effects within a Ionic polymer metal composite (IPMC) actuator (cf. Fig 2) and led to a non linear distributed parameter model validated experimentally. This work will be used as primary work for the modeling of the electroactive structures used as actuator for the endoscope.

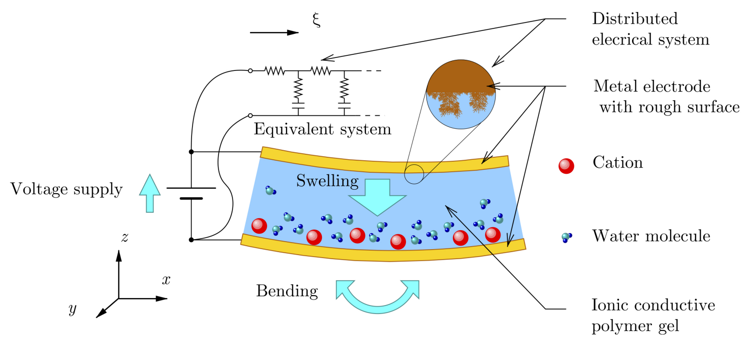

Figure 2: Multi scale modeling of IPMC actuator [4]

The port Hamiltonian approaches have also been advantageously used for the analysis of existence of solutions and stability of distributed parameter systems [5, 6]. Similarly to the finite dimensional case, it has been shown that the structure of the system and its interactions with the environment can be taken into account through a geometric structure named *Dirac structure* [7]. This geometric structure, derived from an appropriate choice of the state and effort variables (especially at the boundary), reflects the energetic properties of the system and the links between its driving forces, its dynamics and energy. This structure is of great interest for the stability analysis. Furthermore, control design techniques developed for non linear and/or distributed parameter systems mainly use the Lyapunov theory whose foundations are based on the notion of energy. Hence the port Hamiltonian approach is naturally well adapted for control design. Designing controllers using passivity and port Hamiltonian formulations consists in shaping the energy or power function (Energy or Power shaping) in closed loop. It is also possible to modify the closed loop interconnection structure as well as the dissipation function in order to obtain a dynamical system with desired behavior. This kind of method is named *Interconnection and Damping Assignment–Passivity Based Control (IDA-PBC)* design method [8]. It has been developed for finite dimensional systems and recently generalised to the boundary control of 1D distributed parameter systems [9]. In both cases, as soon as infinite dimensional systems are considered, one has to reduce the system or/and the controller for real time implementation. The reduction step can be considered after the control design, or can be considered earlier in order to anticipate its effects on the closed-loop dynamics. Among the different existing reduction methods (Finite difference, Finite elements, ...), some of them have been generalised to port Hamiltonian systems [10, 11] with the aim of preserving the geometric structure and the passivity properties of the system during the reduction. This structure preserving approach results in the conservation of materiel and energy balance equations which are very important for control design. They have been successfully used in different applications [12, 13]. There exist also structure preserving reduction methods based on input-output considerations [14]. However, when the system is weakly damped, the implementation of these open loop reduction methods is delicate. Indeed they cannot guarantee that the neglected dynamics are not important in closed loop, leading to undesirable effects when the control derived from the reduced order model is applied to the full state system. This is called the *spillover* effect. Recently a closed loop model reduction method has been proposed in order to design reduced order controllers [15] with guaranteed closed loop performances.

In this thesis, we shall first consider a reduced port Hamiltonian model of the compliant endoscope coupled to the electroactive polymer based actuators. The distributed control strategies will be derived using this reduced order model. Since the structured errors appear naturally in the reduction procedure, the developed controllers shall take these uncertainties into account, for instance by using H_∞ based control design strategies [16]. The link between passivity and small gain theorem [17] will be investigated. Finally, an experimental set-up will be developed by using the experimental resources of the AS2M department in order to test the different control strategies.

Objectives and time planing

This thesis has three main objectives:

- **Modeling**: First, to develop a reliable model of the electro-active polymer taking the multi-physical, non linear and distributed parameters properties into account. This work will be done based on the theoretical results proposed in [4] and adapted to the considered application case (nature of polymer, mechanical structure and environment). The experimental validation will be done using the experimental resources developed in our department.
- **Reduction**: Second, to propose a structure preserving reduction/discretization method and to apply it to this class of systems with control design perspectives [15]. The influence of the physical parameters on the system dynamics and the errors due to the reduction will be studied. The characteristic and number of the actuators will be also investigated.
- **Control design**: Third, to design robust control laws using the reduced order model and taking the approximations due this reduction into account. An experimental set-up will be built in order to test the proposed control design methods.

Candidates profile

- Excellent MSc/Engineer in Automatic Control.
- Strong knowledge background in automatic control and applied mathematics.
- Fluent in speaking and reading English.

Funding and application

3 years duration doctoral contract funded by *Région Bourgogne Franche Comté*. The Ph. D thesis may start in October 2017.

Please send your application documents to both advisers, Pr. Yann Le Gorrec (legorrec@femto-st.fr) and Dr. Yongxin Wu (yongxin.wu@femto-st.fr) including a detailed CV and a cover letter dedicated to the proposed thesis subject.

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