Ph. D. Thesis

Title: Modeling and control of the Dielectric polymer actuator based soft robots using the port Hamiltonian approach

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Context/Aim:

This thesis will take place within the AS2M (Automatique et Systèmes Micro-Mécatroniques) department of FEMTO-ST Besançon. The objective of this thesis is the design, modeling and control of the Dielectric polymer actuator based soft robots using the port Hamiltonian framework.

Key words:

Port Hamiltonian systems; Soft robots; Multi physical systems; passivity based control; Dielectric polymer actuators

Detailed description:

In this thesis, we are interested on the modeling and control of the soft robots based on the Dielectric polymer actuators. The Dielectric polymers have been developed in the recent years and drawn attentions of the robotic community thanks to their different advantages: large deformation, fast response, energy efficacy and free materials, etc [1]. Different robotic applications have been realized based on the Dielectric polymer. The recent ones are: the autonomous untethered fast soft robotic [3], Stretchable pumps for soft machines [4], versatile soft grippers [5]. Dielectric polymer actuators can also be fabricated by different technologies [6,7,8], and it is now possible to realize the flexible electrodes by the jet ink printer [9] making the complex configuration realization possible.

The main objective of this thesis is the ***design, modeling and control of the soft robotic structure to fast pick-put variable form objects.*** The proposed robotic structure will use at first the rolled actuators for arm robotics or the HASEL type of actuators.

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. The port Hamiltonian formalism is particularly well-adapted for the modeling and the control of nonlinear multi physical systems 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 [10]. It allows to represent the different phenomena such as the wave propagation, the convection and the diffusion on the spatial space.

The port Hamiltonian approaches have also been advantageously used for the analysis of the existence of solutions and stability of distributed parameter systems [11,12]. 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. 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 stability analysis. Furthermore, control design techniques developed for nonlinear 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 of shaping the energy or power function (Energy or Power shaping) in the closed-loop. It is also possible to modify the closed-loop interconnection structure as well as the dissipation function in order to obtain a dynamic system with the desired behavior. This kind of method is named Interconnection and Damping Assignment–Passivity Based Control (IDA-PBC) design method [13]. It has been developed for finite dimensional systems and recently generalized to the boundary control of 1D distributed parameter systems [14]. The first extension to the 2D and 3D boundary-controlled systems is now investigating [15]. The observer-based state feedback control laws for distributed parameters port Hamiltonian systems are proposed in [16,17].

Objectives et time planning:

This thesis has three main objectives:

- **Modeling**: First, to develop a reliable model of the soft robot based on the Dielectric polymer actuator with taking into account its multi-physical, nonlinear and distributed aspects.
- **Robot design**: It is interesting to determine the optimal geometry configuration for the soft robot design to achieve the maximal actuation capacity (Contraction force and variable stiffness).
- **Control design**: At last, the position and force control of soft robots will be investigated using the port Hamiltonian approach.

Candidate’s profile

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

Funding and application

3 years duration doctoral contract subjects to funding by le EIPHI Graduate School and Région Bourgogne Franche Comté. The Ph. D thesis may start in October 2021. Please send your application documents to advisers, Pr. Yann Le Gorrec (yann.le.gorrec@ens2m.fr), Dr. Yongxin Wu (yongxin.wu@ens2m.fr) and Dr. Kanty Rabenorosoa (kanty.rabenorosoa@ens2m.fr) including a detailed CV (mandatory), a cover letter dedicated to the proposed thesis subject (mandatory), and the recommendation letters from candidates’ references (if possible).

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