Energy based modeling and control of tubular dielectric elastomer actuators dedicated to cardiac assist device

Context

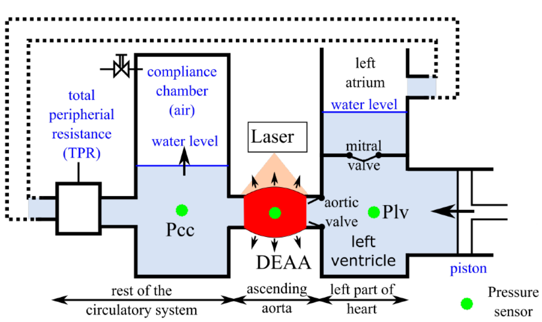
The internship thesis will be a joint work between the Automatique et Systèmes Micro-Mécatroniques (AS2M) department of FEMTO-ST Institute in France and the Integrated Actuators laboratory (LAI) of EPFL in Switzerland, under the funding of International Collegium Smyle program.

The FEMTO-ST Institute (Franche-Comté Electronics, Thermal Mechanics and Optics - Sciences and Technologies, UMR 6174) is a mixed French research unit, placed under the main supervision of the National Center for Scientific Research (CNRS) and the University of Bourgogne Franche-Comté (UBFC). The institute has 7 departments, among which the AS2M department has more than 80 members. The research activities of AS2M department cover automatic control, nano- and micro-robotics, mechatronics, and artificial intelligence. The research group has a strong knowledge of energy-based modeling and control of multiphysical systems, with the application on soft actuators, biomedical robots, and fluid-solid interactions, etc.

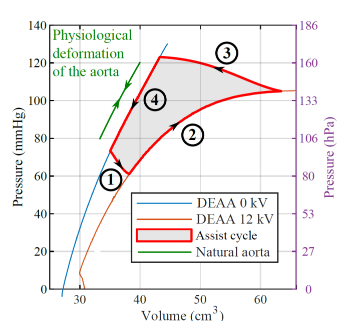
The LAI of EPFL (Ecole Polytechniques Fédérale de Lausanne) is specialized in modeling and design optimization of piezoelectric motors and actuators. Since 2018, with the establishment of the Center of Artificial Muscles (CAM), the LAI has a particular research activity focusing on the design, fabrication and modeling of artificial muscles with the use of electroactive polymer actuators.

Scientific context of the internship thesis

During the last two decades, soft actuators based on electroactive polymers, and more specifically based on dielectric elastomer actuators (DEAs), have known a huge growth of interest in the field of biomedical robotics [1, 2] because of their large deformation, high compliance, low power consumption, and good bio-compatibility. Researchers at LAI have proposed to replace a part of the aorta with tubular DEAs in order to treat the heart failure of patients (see Fig.1a for a schematic representation). The tubular DEA is firstly prestretched because of the blood pressure. With a high voltage (kV) applied on the compliant electrodes of the DEA, the generated Maxwell stress will compress the elastomer along the thickness direction. Following the volume conservation law, the DEA will also deform along the longitudinal and circumferential directions. A measured pressure-volume diagram under three different scenarios is illustrated in Fig.1b. One can obviously notice that with the activation and deactivation of the DEA cyclically, the pressure inside the tube decreases and augments accordingly, which can better assist the systole and diastole of the heart. Main work focuses on the design, manufacture and static modeling of these tubular DEAs [3, 4]. Recently, a dynamic finite dimensional model of this tubular DEA has been proposed which focuses only on the deformation of the center point of the tube [5]. From the fact that the soft DEAs do not deform homogeneously, a more precise model with multiple degrees of freedom is required. This modeling is also important for the future controller design. Moreover, the model of the DEA is nonlinear and multiphysical which contains both the electrical part and the mechanical one, together with their coupling. The port-Hamiltonian framework [6] will be investigated to model the tubular DEA. This framework is based on the energy exchanges within the system and with its environment. Furthermore, the port-Hamiltonian formulation exhibits a nice geometric structure and intrinsic passivity [7], which is useful for the controller design of nonlinear systems.



(a)



(b)

Figure 1: (a) Experimental setup of a flowloop that mimics the cardiac circulation, where 'DEAA' represents the tubular DEA [3]. (b) Measured pressure-volume relation without and with DEAA [3].

The second part of the project concerns the design of a controller. As aforementioned, the applied high voltage reduces the thickness of the DEA, thus augments the electric field. As a consequence, the augmented electric field will continue compress the DEA, leading to a positive feedback. The DEAs will undergo a giant deformation once the applied voltage passes a certain limit. This is known as the typical snap-through instability [8], which is one of the reasons for the breakdown of the DEAs. Researchers in materials science have studied this instability and tried to avoid it by modifying the configuration of the DEAs. We would like to solve this problem in a different way by adding a controller that allows to use the actuator in an optimal way and to prevent its deterioration.

Internship activity

The intern will perform her/his first research activity at the AS2M department. The theoretic model of the DEAs with multiple degrees of freedom under the port-Hamiltonian framework is expected. Then the established model will be validated with the experiments at LAI. At last, the control problem will be investigated.

Administrative information

- Location: AS2M Department, FEMTO-ST institute, Besançon, France & LAI, EPFL, Neuchâtel, Switzerland.
- Starting time: February/March 2022 with a duration of 6 months.
- Supervisors: Dr. Ning Liu (AS2M department), Prof. Yann Le Gorrec (AS2M department), Dr. Yoan Civet (LAI), and Prof. Yves Perriard (LAI).

Application

Candidates must be M2 level (2nd year of MSc or last year of cycle ingénieur) in Automatic control, Mechatronics, Microengineering, or Robotics. The candidate must be proficient in Matlab & Simulink simulation and have excellent programming skills. The knowledge of using Labview software is preferred. In the first interview, the student will have to show that she/he is capable to understand dynamic mathematical models and model analysis. To apply, please send the CV, motivation letter and the transcripts of last two years to Dr. Ning Liu at ning.liu@femto-st.fr. The application of the internship will be closed at the end of January 2022.

Perspectives

Possibility to start a PhD, after the internship. The topic would be modeling and robust control of the dielectric elastomer actuators with distributed parameter port-Hamiltonian systems.

References

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