Closed loop control of a rotational joint driven by two antagonistic dielectric elastomer actuators

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Electroactive Polymers (EAPs) are polymers able to respond to electrical stimulations, modifying their shape when an external voltage is applied to them [1]. For this reason, EAPs are also often called "artificial muscles" because, even if they don't share the same operative principle of biological muscles, their functional response is similar. Dielectric Elastomer Actuators (DEAs) represent one promising class of electroactive polymers that offer great potentials for mechatronic and robotic applications, especially in the field of biomimetic mechanisms and humanoid robotics [2]. Since DEs are basically constituted of soft, rubber material (hence the name elastomers), actuators based on this technology are intrinsically compliant, making their use potentially advantageous when a safe, compliant interaction with the surrounding environment is required. Compared to many other EAPs, moreover, dielectric elastomers actuators are able to produce high strains and forces, and respond to externally applied electrical stimuli with fast operation cycles.

In this work we explore the controllability properties of a simple rotational joint driven by two dielectric elastomer actuators arranged in an antagonistic configuration (Figure 1). The setup consists of two parallel DEAs moving a bar. On one side, the actuators are linked to a fixed base. On the other side, the movement of the artificial muscles is transmitted to a pulley through a stainless steel tendon. An aluminum bar is rigidly linked to the pulley.

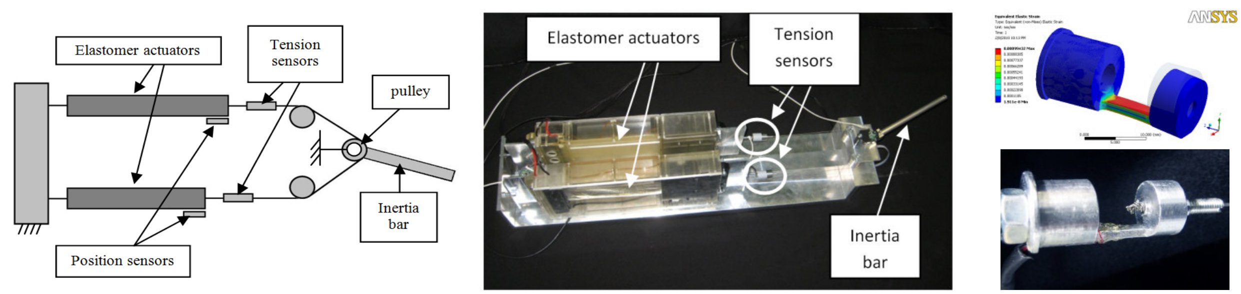

Figure 1: sketch (a), and picture of the experimental setup (b). Two dielectric elastomer actuators arranged in antagonistic configuration are employed to move a pulley, on which a link is attached. Position sensors and tension sensors are employed to measure the displacement and the forces developed by the actuators (c).

Even if far from being a close reproduction of the human musculoskeletal system, this structure has some analogies with its typical arrangement, in which the position of one joint is controlled through the activation of two (or more) muscles. In our simplified artificial system, the two actuators have the functionality of an antagonistic pair of muscles, whose levels of activation determine the angular position of the inertia bar.

Since the two elastomer actuators are intrinsically compliant, a sensorized tendon tension system, based on semiconductor strain gauges, has developed used to both adjust the preload of the muscles and measure the tension of the two tendons. Taking advantage of the measurement of forces developed by the two artificial muscles, a closed loop controller has been implemented. The proposed approach consists of two PID regulators for independent tendon tension control, and an external joint position control loop, which generates the reference input signal for the previous force controllers. In this way, a coordinated motion of the actuators allows to achieve the primary task of position control of the joint, while guaranteeing a minimum tendon tension.

Finally it must be noticed that the stress-strain relationship of the artificial muscle actuators is intrinsically not linear (due to the mechanical properties of the elastomer material) while the actuator's stiffness depends on the externally applied voltage (Figure 2). According to these properties, the resulting stiffness of the joint can be modified, although in a small, limited range, by changing the level of co-activating of the two muscles.

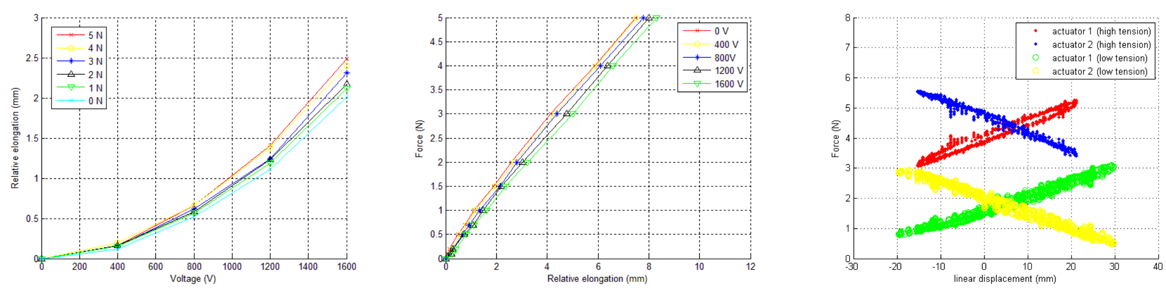

Figure 2: Voltage-elongation (a) and force-elongation (b) relationship of one of the two elastomer actuators, expressed as a function of an externally applied load and an externally applied voltage respectively.

Summary / proposal for Workshop presentation:

We want to discuss the use of Electroactive Polymers in an agonistic/antagonistic configuration to perform position tasks of one joint. Experiments that show the performances of one single actuator will be presented. Force measurements, using custom made load cells and linear position sensors, are exploited to characterize the non-linear stress-strain relationship of the system. It will be also shown how to employ force feed-back to control the tension of two tendons, using a closed loop regulator that guarantees a minimum desired preload while achieving the position task. Finally, the ability of the system to change its stiffness by co-activating the two muscles will be discussed.

[1] Bar-Cohen, Y.; "*Electroactive polymers (EAP) actuators as artificial muscles – reality, potential and challenges*", SPIE press, Washington , (2004).

[2] Carpi, F., De Rossi, D., Kornbluh, R., Pelrine, R., Sommer-Larsen, P.; "*Dielectric Elastomers as Electromechanical Transducers*", Elsevier , (2008).