Precision Control of Ionic Polymer-Metal Composite Actuators

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Keywords : Ionic polymer-metal composites, electroactive polymer, smart (active) material, control systems

Type of presentation: **Invited Talk**

Ionic polymer-metal composite (IPMC) material is an innovative active (smart) material that has recently been explored for applications that include artificial fish-like propulsors, robotic manipulators, biomedical devices, and sensors in prosthetic systems[1-3]. In particular, an IPMC actuator is soft and flexible, can be driven with low voltage (<5 V), and can operate in an aqueous environment. Typically, an IPMC is created by plating a noble metal (e.g., platinum) on both sides of a thin ionomeric membrane, followed by a process that neutralizes the material with a certain amount of cations to balance the electrical charge of the anions covalently bonded to the backbone polymer [4]. Compared to conventional metal- or ceramic-based actuators, such as shape memory alloys and piezoelectric ceramics, IPMCs are lightweight, low power, fracture tolerant, and easily manufactured and configured into complex shapes. Unfortunately, the behavior of IPMC actuators exhibits several undesirable effects that include back-relaxation, induced structural vibration, and time-varying nonlinear behaviors [5]. All these behaviors combined can limit the performance of IPMC-based actuators, and thus require active control for precision positioning.

This talk focuses on control approaches that offer the ability for precision control IPMC actuators. Firstly, vibration-induced effects are compensated for using a model-based approach that considers the frequency-dependent input-output behavior of the IPMC [5]. In this approach, an inverse model is used to determine feedforward inputs that precisely track a desired output trajectory (see Fig. 1(a)). Such an approach exploits the system model for finding control inputs that compensate for deficit performance.

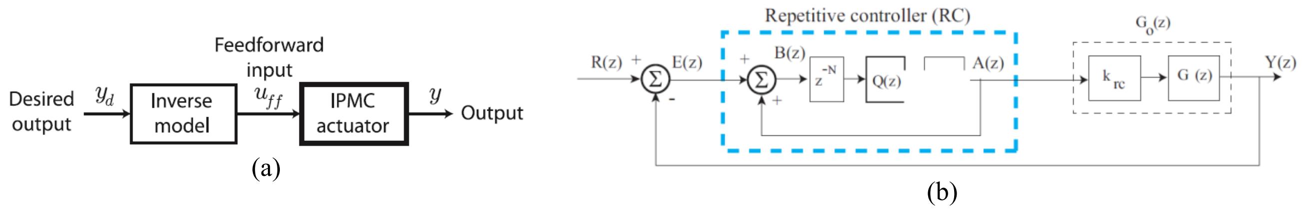

Figure 1. (a) Feedforward control concept and (b) a repetitive control scheme for IPMC actuators.

For applications that require tracking of a periodic trajectory, such as the scanning motion of IPMC-based active endoscopy, a repetitive control approach is presented [6]. This feedback-based control technique takes advantage of the process of repetition for precision positioning (Fig. 1(b)). Finally, to mitigate the back-relaxation effect, a master-slave control approach is proposed and applied to patterned IPMCs [7,8]. The patterned IPMCs are created by carefully isolating patterns of electrodes on the surface of the polymer-metal composite, where sections of the composite can function as an actuator, while other areas can be used for sensing deformation and responses to external stimulation (see Fig. 2).

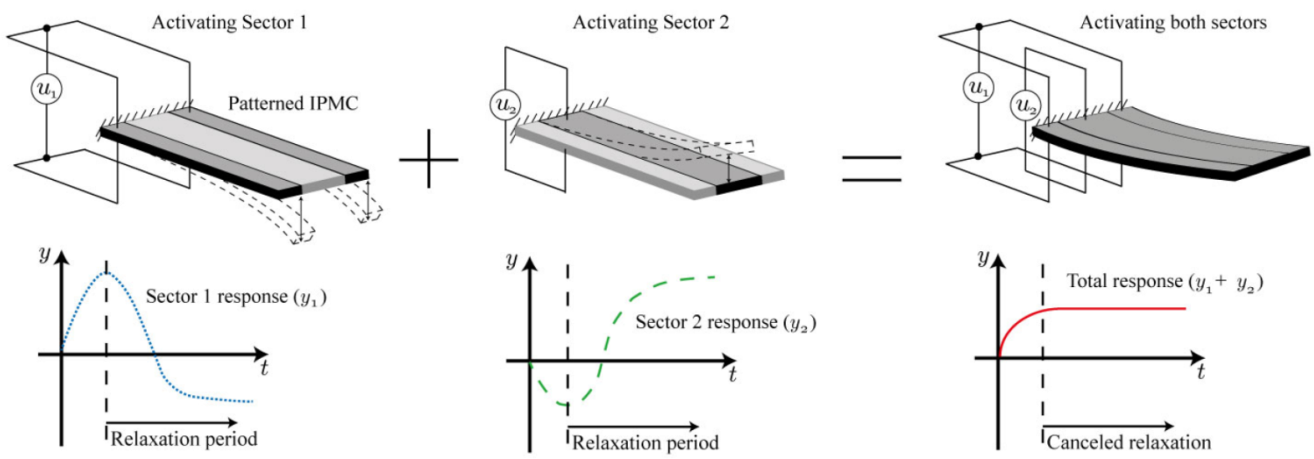

Figure 2. Control of patterned IPMC to mitigate IPMC back-relaxation effect. Each sector is independently controlled to produce a net canceling effect [8].

The details of the manufacturing, modeling, and control of IPMCs are discussed. Experimental results are presented for the different control schemes to demonstrate their ability for precision positioning. Technical design challenges and performance limitations are also discussed.

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