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Position control of ionic polymer metal composite actuator using quantitative feedback theory

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ABSTRACT

An ionic polymer metal composite (IPMC) is an electro-active polymer (EAP) that bends in response to a small applied electrical field as a result of mobility of cations in the polymer network and vice versa. Recently, IPMC is widely applied in many fields such as biometric, biomedical and micro-manipulator fields. This paper proposes a robust position controller for IPMCs which is based on the quantitative feedback theory (QFT). Firstly, the IPMC actuation was investigated. The PRBS input voltage signals were applied to the IPMC in order to identify the system characteristic. Consequently, the QFT controller for the IPMC was designed from the identified IPMC model. Experiments were carried out to validate the effectiveness of proposed controller applied to the IPMC.

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1. Introduction

An ionic polymer metal composite (IPMC) is an electro-active polymer (EAP) that bends in response to a small applied electrical field as a result of mobility of cations in the polymer network [1] and vice versa. A typical IPMC sheet is constructed with a thin ionic polymer membrane and two metal electrode layers outside. When a low voltage electrical field is applied, the transport of hydrated cations within the IPMC and the associated electrostatic interactions lead to bending motions of the IPMC sheet. Thus, an IPMC can work as a small size actuator. Fig. 1 illustrates the operating mechanism of an IPMC as an actuator. On the other hand, it has been found that an IPMC has an attractive characteristic called ‘sensing’ behavior in which the IPMC generates a low voltage between the two electrodes when it is mechanically bent. The generated voltage is due to the non-uniform concentration of ions in the IPMC membrane. Fig. 2 shows the operating principle of an IPMC as a voltage generating motion sensor.

Because of the low driven voltage, flexible operation, and self sensing ability, IPMC has been widely applied in many micro-applications such as snake-like robot with IPMC actuator [2], micro-pump [3], scale biped walking robot [4], underwater micro-robot [5], etc.

Contrary to the above favorable features, IPMC as a type of piezoelectric actuator has disadvantages about its hysteresis and creep behaviors. Moreover, the characteristics of IPMC are variant largely which depends on the working conditions. Hence, these features may lead to oscillation and instability in the system performances, especially in applications that require high precision such as biomedical applications [6], micro-manipulators [7], etc. To deal with these difficulties, some control strategies have been proposed for IPMC actuators. For example, an impedance control [8], or an integrator anti-windup scheme to reduce the performance degradation due to actuator saturation [9] have been integrated to proportional-integral-derivative (PID) algorithm to perform control targets. Other methods such as a linear quadratic regulator (LQR) [10], genetic algorithm [11], or model reference adaptive control algorithm with IPMC black box model [12] or white box model [13] have been also used. In order to investigate the robustness of an IPMC system, La and Sheng have simulated a robust adaptive control for one type of IPMC [14] while Chen and Tan [15], suggested a robust H_∞ controller for a white box model to achieve a robust response. Although the proposed white box model performed well, it required precious parameters for the actuating system that caused a big challenge to use this method. To overcome this difficulty, a black box model was introduced in [16]. However, the performance was simply investigated through step response only while a full set of testing cases are needed to evaluate a designed controller.

From the unique characteristics of IPMCs as well as their control challenges, this paper proposes an effective solution for IPMC

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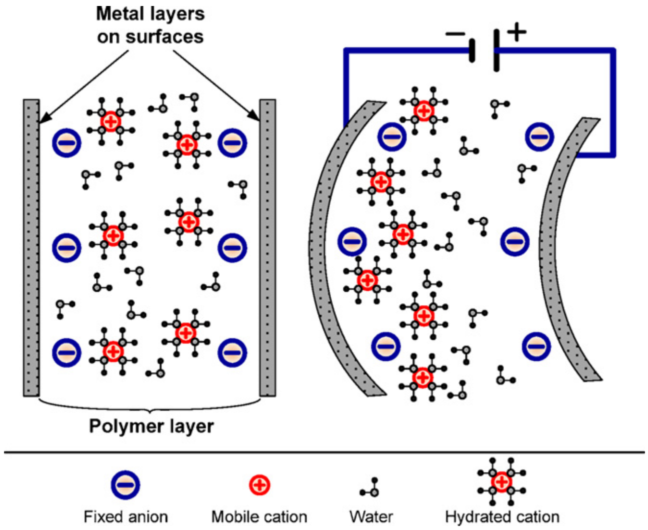

Fig. 1. Operating fundamental of an IPMC as an actuator.

position control with high precision by using quantitative feedback theory technique. The QFT is suited to feedback design for systems with large parameter uncertainties [17]. The QFT technique has been successfully applied to solve many engineering problems, including robot position control [18], flight control actuators [19] and manufacturing systems [20], etc.

In this research, the QFT was applied to design a position controller for one dry type IPMC actuator. The design process contained two parts: a derivation of a nominal plant model with the uncertain bounds for the dynamics of the IPMC and a position control loop design based on the QFT. The controller was designed to satisfy the robust performance requirement, tracking performance specification, and noise attenuation requirement. Experiments have been carried out to show the high robustness of the control performance even in the varying external noise as in real working conditions.

The remainder of this paper is organized as follows: Section 2 describes the apparatus of the IPMC actuating system. In Section 3, the procedure of designing a robust position controller using the QFT technique is presented and Section 4 shows the experimental results of the IPMC position control. Concluding remarks are presented in Section 5.

2. Experimental apparatus

This section gives a description of a test rig for the IPMC position control performance as shown in Fig. 3. As seen in this figure, the actuator is a sheet of IPMC (size of 40 mm × 6 mm × 0.2 mm) manufactured by Environmental Robots Inc., and can operate in both the wet and dry environments. The processing system was built on a personal computer (Intel® CoreTM2 Duo 1.8 GHz) within Simulink environment combined with Real-time Windows Target Toolbox of MATLAB. Two multi-function data acquisition Advantech cards,

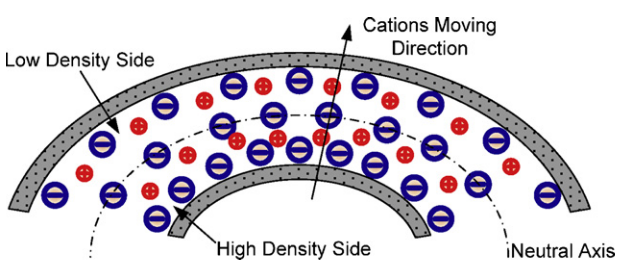

Fig. 2. Sensing fundamental of an IPMC as a sensor.

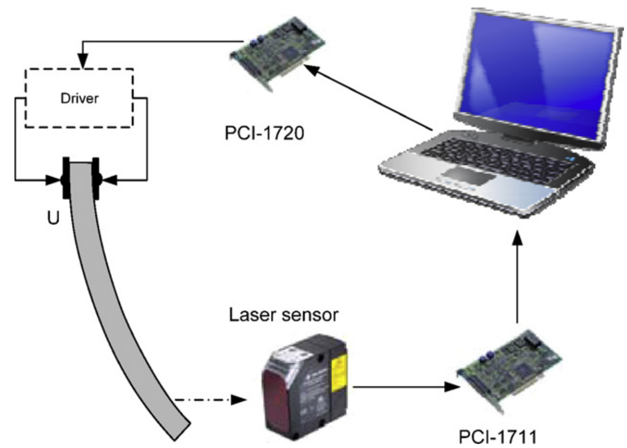

Fig. 3. IPMC actuation configuration.

A/D 1711 and D/A 1720, were installed on the PCI slots of the PC to perform the peripheral buses. In addition, a CCD laser displacement sensor, LK-081, from Keyence Corp. was used to measure and feedback the IPMC tip displacement. Setting parameters for the IPMC control system are listed in Table 1 and the apparatus is displayed in Fig. 4.

In position control task, the IPMC operation is decided by the voltage applied to the two electrodes at the end of the IPMC sheet (see Fig. 3). This voltage is adjusted by the control signal which is sent from the processing system on the PC to the IPMC driving circuit through the 1720 D/A converter. At the same time, the IPMC tip displacement measured by the laser sensor is sent back to the PC through the 1711 A/D converter. On the PC, the controller processes the feedback signal in order to perform and send a command to the IPMC system for the coming step, consequently, performs a closed-loop position control system.

Table 1
Setting parameters for the IPMC system.

Parameters	Specifications
Operating environment	Dry environment
Max operating frequency	0.05 Hz
Sampling time	0.001 s
Driving voltages	3–5 V
Max driving current	1 A

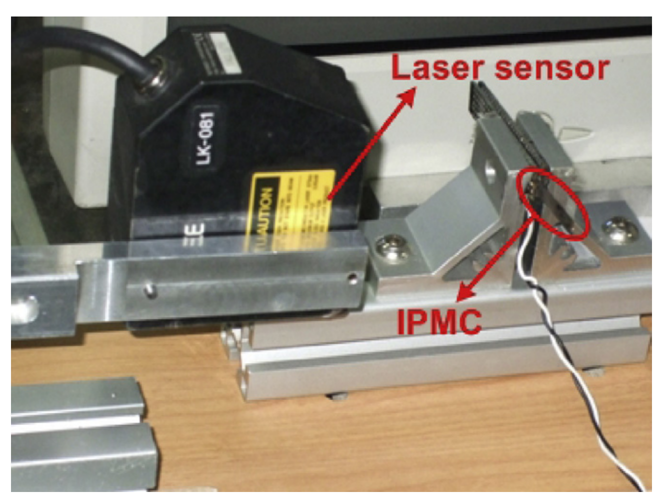

Fig. 4. IPMC actuation apparatus.

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