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Identification of an ionic polymer metal composite actuator employing Preisach type fuzzy NARX model and Particle Swarm Optimization

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ABSTRACT

An ionic polymer metal composite (IPMC) actuator 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. One drawback of IPMC in the use of sensors and actuators is the existence of strong hysteresis effects, nonlinearities, and uncertainties. The aims of this paper is the identification of a nonlinear black-box model for IPMC actuators based on a novel Preisach type fuzzy Nonlinear Auto Regressive Exogenous (NARX) model and modified Particle Swarm Optimization (PSO).

Firstly, an IPMC actuator is investigated. The open-loop input voltage signals are applied to the IPMC in order to investigate the IPMC characteristics. Secondly, a proper Preisach type fuzzy NARX model is developed with one input and one output to estimate the IPMC tip displacement. By employing the collected training data, an identification scheme based on incorporation of least squares method and Particle Swarm Optimization (PSO) algorithm is then carried out to tune the model parameters. Finally, modeling results proved the ability of proposed scheme to estimate the bending behaviors of IPMC actuators.

1. Introduction

During the recent decade, ionic polymer metal composite, as a smart material, is gaining great importance in the use for both sensors and actuators. An IPMC is an electro-active polymer (EPA) which is constructed of a thin ionic polymer membrane and two metallic electrode layers outside. The advantages of IPMC are bending in response to a small applied electrical field as a result of mobility of cations in the polymer network [1] and vice versa [2,3].

Operating principle of IPMC can be described as follows. When a low 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. On the other hand, when the IPMC is mechanically bent, it generates a low voltage between the two electrodes due to the non-uniform concentration of ions in the IPMC membrane. Thus, IPMC can work as both small size actuators and sensors [4–6]. Fig. 1 illustrates the operating mechanism of an IPMC. Because of the low driven voltage, flexible operation, and self sensing ability, IPMC material has been widely applied in many micro applications such as a snake-like robot with IPMC actuator [7], a micro pump [8], a scale biped walking robot [9], an underwater micro robot [10], etc.

Contrary to the above favorable features, IPMC as a type of smart material has disadvantages about its hysteresis, nonlinearities, and uncertainties. These challenges can be shown clearly as in Fig. 2, where the open-loop responses of the IPMC actuator corresponding to the step, square, and sinusoidal input signals are investigated. As shown in Fig. 2(a), the open-loop step responses rise rapidly but decay slowly without maintaining a steady state. This is called straightening-back phenomena of IPMC actuators [11]. Also, the creep behavior exists in IPMC actuations with both square and sinusoidal input signals as shown in Fig. 2(b) and (c). Moreover, the IPMC characteristic variants largely depend on working conditions, i.e., temperature, humidity, and conductivity of electrodes. These features may lead to oscillation and instability in IPMC system performances, especially in applications that require high precision such as biomedical applications [12], micro-manipulators [13], etc.

Since the IPMC faces such above challenges, it is important to develop an accurate IPMC model to investigate the IPMC bending characteristics as well as to apply to system control for IPMC actuator. To deal with hysteresis problem, the famous Preisach operator [14] has been employed to describe the rate dependent behavior in SMA [15] and magnetostrictive [16] actuators. For describing the bending behavior of IPMC actuators, Chen et al. [17] presented a hybrid model based on a Preisach operator and a creep model. However, the accuracy of modeling results has not been successfully carried out. In another trend, to access the nonlinearities and uncertainties in complex system, Ahn and Anh [18] have successfully developed a Nonlinear Auto Regressive Exogenous (NARX) model

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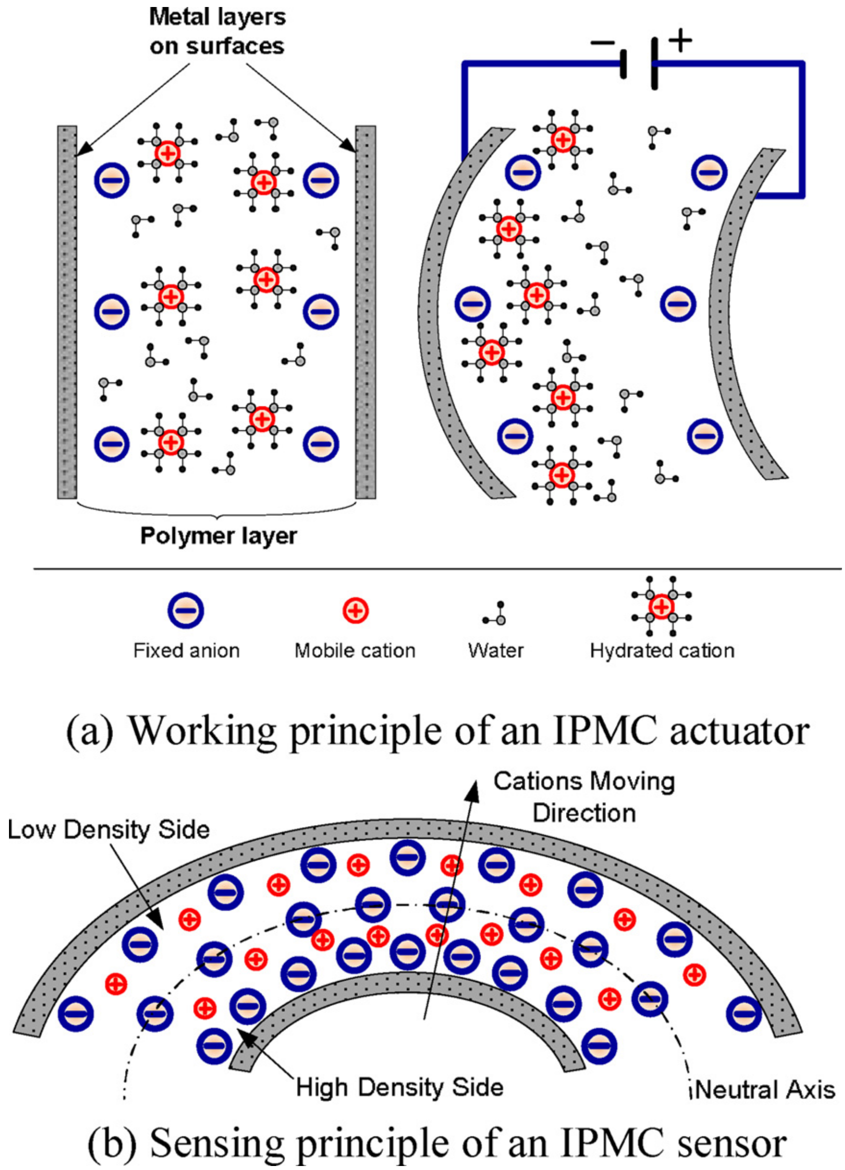

Fig. 1. Fundamental of IPMC as actuators and sensors.

based on fuzzy algorithm for identification of pneumatic artificial muscle (PAM) manipulators. Although this scheme is able to describe the behaviors of PAM manipulators, there was no attempt to combine the fuzzy NARX model with other hysteresis models to describe the hysteresis effects, nonlinearities and uncertainties in IPMC actuators.

Based on the advanced features of IPMC and demands for IPMC modeling methods, the topic of this paper is to develop an accurate nonlinear black-box model (NBBM) for describing the IPMC bending behavior by combining the famous Preisach operator in cascaded with a fuzzy NARX model and employing the Particle Swarm Optimization (PSO) in the identification process. Main contributions of this paper are:

1. The combination of a Preisach operator and fuzzy NARX structure for modeling of an IPMC actuator is newly proposed and constructed. The combination of the *rate-independent* hysteresis characteristic of Preisach operator, the excellent approximating capability from the fuzzy system, and the predictive potentiality from the NARX structure brings powerful modeling abilities to the proposed Preisach type fuzzy NARX system.
2. An identification scheme for the proposed model is developed. The identification procedures consist of two stages. Firstly, parameters of the Preisach operator are identified by investigating response of the IPMC actuator corresponding to *first order reversal input signals*. Then, the unknown parameters of fuzzy NARX structure are updated by employing the Particle Swarm Optimization (PSO) algorithm.
3. The identification process is done carefully to obtain correct parameters. Finally, validation results are carried out to evaluate the effectiveness of the proposed modeling method and identification scheme for one particular type IPMC actuator.

The remainder of this paper is organized as follows: Section 2 presents the procedure of designing the accurate nonlinear black-box model. In Section 3, the identification procedures of the IPMC actuator are described, while Section 4 shows the modeling results of the designed NBBM. Concluding remarks are presented in Section 5.