Operator-Based Robust Nonlinear Control for Ionic Polymer Metal Composite with Uncertainties and Hysteresis

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Abstract. The ionic polymer metal composite (IPMC) belongs to the category electroactive polymers (EAP), many potential applications for low-mass high-displacement actuators in biomedical and robotic systems have been shown. But identification of some physical parameters for nonlinear IPMC models is still a difficult issue. Moreover, hysteretic behavior exists in IPMCs and affects the performance of actuators, even makes the system with these actuators exhibit undesirable oscillations and instability. In this paper, a new nonlinear model of the IPMC with uncertainties and hysteresis is obtained. According to hysteresis and uncertainties for the proposed model, a nonlinear robust control using operator-based robust right coprime factorization is designed for the IPMC. The effectiveness of the proposed method is confirmed through simulation and experiment.

Keywords: IPMC, Uncertainties, Hysteresis, Nonlinear Control, Right Coprime Factorization, Robust Stability.

1 Introduction

Various electroactive polymers (EAP) materials, also called artificial muscles, are being developed to enable effective, miniature, light and low power actuators. The Ionic Polymer Metal Composite (IPMC) belongs to the category electroactive polymers (EAP). An IPMC sample consists of a thin ion-exchange membrane (e.g., Nafion) plated on both surfaces with a noble metal as electrodes. Because IPMCs are capable of producing large deformation under a low driving voltage, they have been shown to have many potential applications as biomimetic robotic distributed sensors, actuators, transducers, artificial muscles and so on [1, 2].

Several linear and nonlinear models have been proposed in precision displacement control [3, 4]BThe linear models are often obtained from approximate method, for linear models, linear quadratic regulator (LQR), proportional integral and derivative (PID), adaptive fuzzy algorithm and impedance control

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scheme are usually used in position control for linear models [5, 6]. The IPMC mainly shows nonlinear behaviors, but identification of some physical parameters is difficult in practice. Some physical parameters are small enough the influence for displacement deformation in practice, which can be ignored and considered as uncertainties in the model. According to variables ignored and measurement error of parameters, an improved nonlinear model with uncertainties is obtained. Moreover, hysteretic behavior exists in IPMCs and affects the performance of actuators [7], even makes the system with these actuators exhibit undesirable oscillations and instability. In order to make hysteresis model closer to the real hysteretic behavior, a symmetric PI hysteresis model which is described by symmetric play hysteresis operator with unknown slopes is given.

In precision position control, IPMC actuator has to move from one specified position to another, and has to maintain the position constant. It needs a skilful operator to control manually based on his or her experiences to stop the swing immediately at the right position. To resolve this problem, operator-based robust right coprime factorization is proposed in this paper. It is well known that coprime factorization has been a promising approach for analysis, design, stabilization and control of nonlinear system [8, 9]. Especially, robust right coprime factorization has attracted much attention due to its convenient in researching input-output stability problems of nonlinear system with uncertainties [10, 11, 12, 13]. As a result, there exits hysteretic behavior and some uncertainties for the proposed nonlinear model, the nonlinear IPMC position control system is considered by using robust right coprime factorization approach in this paper, robust right coprime factorization and its application to a nonlinear IPMC control setup are investigated.

The outline of the paper is given as follows. In Section 2, experimental system is described. In Section 3, modeling and problem statement are introduced. In Section 4, robust right coprime factorization approach is presented for an IPMC set. The simulation and experimental results are shown in Section 5, and Section 6 is the conclusion.

2 Experimental System

Fig. 1(a) shows picture of experimental system. The experimental system schematic illustration is shown in Fig. 1(b). In this experimental system, an IPMC sample of dimensions 50 mm 10 mm 0.2 mm is clamped at one end, and is subject to voltage excitation generated from the computer and board (PCI-3521). A laser displacement sensor (ZX-LD40: 40±10mm) is used to measure the bending displacement d. The relationship between the bending curvature $1/\rho$ and the displacement d can be described by (see Fig. 2):

$$\frac{1}{\rho} = \frac{2d}{d^2 + h^2}. \tag{1}$$

where, h is the vertical distance.