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Shape estimation of IPMC actuators in ionic solutions using hyper redundant kinematic modeling

Ritwik Chattaraj [a,*], Siladitya Khan [b], Srijan Bhattacharya [b], Bikash Bepari [c], Debabrata Chatterjee [d], Subhasis Bhaumik [a]

[a] School of Mechatronics and Robotics, Indian Institute of Engineering Science and Technology, Shibpur, 711103 Howrah, India
[b] Department of Applied Electronics and Instrumentation Engineering, RCC Institute of Information Technology, Kolkata 700015, India
[c] Department of Production Engineering, Haldia Institute of Technology, Haldia 721657, India
[d] Chemistry & Biomimetics Group, CSIR-CMERI, Durgapur, Burdwan 713209, India

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ABSTRACT

Ionic Polymer Metal Composites (IPMCs) has established itself as an ionomer rendering wide-ranging applications spanning the paradigm of robotics to medical appliances, thereby drawing significant research interests. Prior studies to characterize IPMCs have been conducted over several years but efforts on its kinematic modeling have remained inchoate. The bending profile of IPMC changes when placed in different ionic solutions. The IPMC trace along with its tip location characterizes its complete behavior upon low level actuation. This article aims at identifying the bending patterns of an IPMC actuator, decomposing it as a 20-link hyper-redundant serial manipulator. The Tractrix based inverse kinematics engine is used to study the polymer profile in distilled water, 1.5 N LiCl and NaCl solutions respectively. The proposed algorithm yields a natural curve (Tractrix) which resembles the profile traced by an actuated IPMC strip — enabling its use in potential applications which would require a foresight of the actuator workspace.

1. Introduction

The field of bio-mimetic technology demands actuators of biocompatible nature, which has triggered a tremendous surge in the use of smart materials/smart actuators for diverse applications ranging from robotic grippers for micro manipulation to biomedical devices. Electro-active polymers or (EAPs) are smart materials which exhibit large scale deformation when subjected to a variation in electric field. An Ionic Polymer Metal Composite (IPMC) is one such EAP comprising of a conducting polymer membrane plated by two electrodes that are infused with a solvent. A voltage difference across the electrodes generates an electric field that gives rise to a number of concurrent microscopic actuations culminating in deformation of the IPMC at a visually macroscopic level, demonstrated by Shahinpoor and Kim followed by Bar-Cohen, Bhandari and Lughmani et al. [1–4]. A.J. McDaid et al. [5] explored and developed an adaptive nonlinear model called Iterative Feedback Tuning (IFT) for IPMC actuators. The proposed methodology was seen to deliver better results when its performance was evaluated against an existing standard Proportional-Integral-Derivative algorithm (PID). Overall information regarding the design and development of an IPMC actuator can be found in the review paper by Choonghee Jo et al. [6] which describes the state of art development in modeling techniques to ensure the viability of IPMC actuators in real world problems. Nonlinear modeling including quantification of hysteresis and

* Corresponding author.
E-mail addresses: ritwik.chattaraj@gmail.com (R. Chattaraj), sldtkhan@gmail.com (S. Khan), srijaneie@gmail.com (S. Bhattacharya), bikashbepari@gmail.com (B. Bepari), dchat57@hotmail.com (D. Chatterjee), sbhaumik_besu@yahoo.co.in (S. Bhaumik).

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creep effects of a conducting polymer actuator, forming a two finger gripper using Kelvin–Voigt visco-elastic structure was investigated in [7]. A resonant frequency model based on the theory of cantilever beams for a conducting Polypyrrole (PPy) polymer, varying four controllable parameters namely length, width, polymer thickness, and tip mass have been investigated by John et al. [8] to optimize actuator behavior as a function of its geometry. Alici et al. [9] presented nonlinear parametric models relating the voltage input to cylindrical coordinates of tip deflection of a PPy actuator. Mohsen Annabestani et al. [10] developed a black box model using Adaptive Neuro-Fuzzy Inference System (ANFIS) to predict the displacement of the IPMC tip for an applied voltage input. The data obtained to train the ANFIS network is attained by tracking the tip location of the IPMC actuator using a camera system. A variety of electrical signals were applied to prepare the dataset for the training process. Srijan et al. [11,12] reported an exhaustive characterization of mechanical properties for an IPMC actuated micro gripper and developed a parametric model employing statistical tools to arrive at regression equations relating displacement and actuation force with voltage and frequency.

Most of the principles discussed above engage cantilever bending, which consider deflections to the order of 20% of actuator lengths and are concerned with the tip displacement rather than the overall shape of the actuator in space, however such models fail to present the true dynamic nature of IPMC's since they can deflect as high as 50% of its actuator length. In an attempt to resolve this problem, researchers have embarked on modeling such smart actuators as flexible manipulators with large number of small rigid links. Most of them derive motivation from mechanisms at work in nature's foray namely octopus arm being modeled as a 2D array of 20 segmented links [13], design and control of a 3D eel-fish like robot based on the principle of hyper redundancy [14], kinematics of artificial bacteria flagellum [15], construction and analysis of an elephant trunk robot comprising of 16-two degree of freedom joints [16]. Suzumori et al. [17] investigated the cooperative control of Flexible Micro Actuators (FMA) which computes the homogenous transformation matrix of successive FMAs. Rahim Mutlu et al. [18] presented an effective approach to estimate the shape of EAP in space using the soft robotic manipulator approach. They proposed a novel angle optimization method to solve the inverse kinematic model thereby predicting the EAP's profile for a given voltage input. Ghosal et al. [19] exploited the classical Tractrix curve [20] which originates from the notion of an object starting off with a vertical offset being dragged along a horizontal line and extended it in 3D space to resolve redundancy in serial multi-body systems. For a chosen arbitrary position of the end effector the motion of all other links is solved using the solution of Tractrix. Once the end effector positions are known the joint angle configurations are computed using simple vector algebra thereby creating an effective solution to resolve redundancy. The algorithm was validated on a prototype eight-link hyper-redundant manipulator. A revisit to the above approach by S. Sreenivasan et al. [21] illustrated the simulations of a moving snake, tying knots with a rope and presented an inverse kinematic solution of a planar hyper-redundant manipulator based on the Tractrix. Visualizations of the same were found to be more realistic since displacement of the links diminished gradually from head to tail.

The present discourse investigates the possibility of a novel approach to kinematically model IPMC actuators using Tractrix based algorithms. Maryam et al. [22] discussed the issue of increased efficacy of IPMC actuator due to the effect of various ionic solutions. They established that IL (Ionic Liquid) based actuators incorporating Li^+ exhibit greater displacement at the tip compared to other solutions. The advantage of using IPMC as an EAP is that it can be used both in air as well as in water. However its performance degrades when it is dry i.e. in air. IPMCs with various solvents (Deionized water (DI), Deuterium Oxide (D_2O), Dimethyl Sulfoxide (DMSO)) were tested for measurement of solvent loss and actuation force by Soon-Gie Lee et al. [23]. Ionic polymer membrane can absorb water molecules and several kinds of cations, like H+, Li+, Na+, or K+, among these Li+ ion demonstrate best performance in displacement and force generation [1,24–25]. Based on the literature review the following mediums namely NaCl and LiCl each of strength 1.5 N and distilled water has been selected as dopants for IPMC actuation in this study.

The primary contribution of this study is to propose an effective methodology to solve the hyper redundant kinematics of an IPMC, approximated as a multi-link robotic manipulator. The proposed method ensures that a natural curve is yielded which imitates the actuator profile in different solutions without putting additional restrictions on the joint movements and boundary conditions. A vision based technique to track the actuator movement by means of a passive colored marker has been used considering the compensation of perspective errors arising from the camera. The variation of shape of the IPMC when placed in aforementioned solutions has been presented for identification.

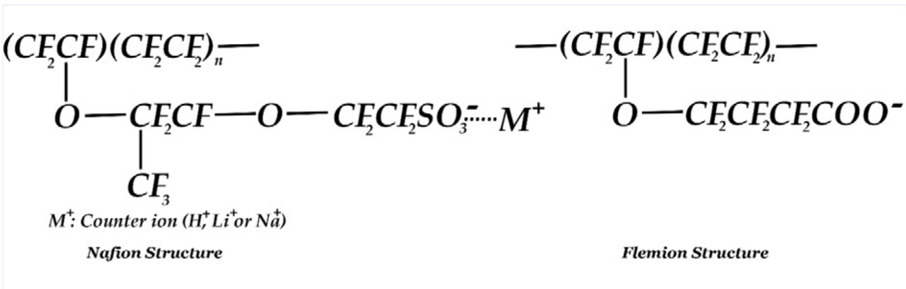

Fig. 1. Chemical structure of Nafion and Flemion.