On the Thrust Efficiency of an IPMC Actuated Robotic Swimmer: Dynamic Modeling and Experimental Investigation

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ABSTRACT
An efficiency model for a biomimetic robotic swimmer that propelled by an ionic polymer-metal composite (IPMC) actuation is proposed in this paper. The model incorporates both hydrodynamics of IPMC and the flexible fin of robotic swimmer, and the actuation model of IPMC has been presented. The parameters of the model were derived through fundamental character of IPMC. Robotic swimmer experiments are conducted on a towing system to validate the model. The thrust force, power consumption were simultaneously measured on the experimental device. The results showed that the model can well predict the thrust efficiency of the robotic swimmer under varied actuated frequencies. According to the experiment data, the highest measured efficiency is $2.4 \times 10^{-3}$, and it has an optimal point when the operating frequency approximates 1 Hz. The model is available for the optimal design of the IPMC-actuated robotic swimmer to achieve better thrust performance and higher thrust efficiency.

KEY WORDS: Biomimetic robotic fish; hydrodynamic modeling; thrust efficiency measurement; ionic polymer-metal composites.

INTRODUCTION
The use of smart material has significantly attributed to the development of biomimetic underwater robot and the micro-robots (Morgansen et al., 2007; Yu et al., 2004; Borgen et al., 2003; Rossi et al., 2011; Tangorra et al., 2007). Ionic Polymer Metal Composites (IPMCs) are innovative materials made of an ionic polymer membrane with plated gold as electrodes on both sides chemically (Shahinpoor and Kim, 2001, 2005). See Fig. 1. The most interesting characteristics of IPMC are its softness and lightness; moreover, they bend as an electric field is applied across their thickness and, vice versa, they generate a detectable voltage if subjected to a mechanical deformation. Briefly, it has the advantages of low activation voltage actuation (1-2V), limited power consumption, low noise, and high flexibility.

Fig.1 Illustration of IPMC operating principle

Plenty of works on IPMC have been reported in recent years. Shahinpoor put forward the first concept of underwater robot using ionic polymers (Shahinpoor, 1992). Woosoon Yim and Kwang J Kim proposed the analytical framework of the modeling dynamic characteristics of IPMC actuator for aquatic propulsor applications (Lee and Kim, 2007). This method can be used for modeling the IPMC actuator in a single or multi-segment form operating in the water. The first model for IPMC-propelled robotic swimmer that captures the intrinsic actuation physics of IPMC, and the complex hydrodynamic interactions between IPMC and fluid, was presented by Tan, where a impedance model was also developed and used to predict the bending