Sub-millilitre Microbial Fuel Cell Power for Soft Robots

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Abstract. Conventional rigid-body robots operate using actuators which differ markedly from the compliant, muscular bodies of biological organisms that generate their energy through organic metabolism. We consider an 'artificial stomach' comprised of a single microbial fuel cell (MFC), converting organic detritus to electricity, used to drive an electroactive artificial muscle. This bridges the crucial gap between a bio-inspired energy source and a bio-inspired actuator. We demonstrate how a sub-mL MFC can charge two 1F capacitors, which are then controllably discharged into an ionic polymer metal composite (IPMC) artificial muscle, producing highly energetic oscillation over multiple actuation cycles. This combined bio-inspired power and actuation system demonstrates the potential to develop a soft, mobile, energetically autonomous robotic organism. In contrast to prior research, here we show energy autonomy without expensive voltage amplification.

Keywords: Microbial fuel cell, artificial muscle, energetic autonomy.

1 Introduction

Current robotics research is focused on combining self-fuelling mechanisms with robust mechanical designs, resulting in systems that can operate, unassisted, in terrain too hostile or inaccessible for humans [1]. The EcoBot robot series utilises rigid MFC technology, with raw organic fuel, to power conventional electromechanical actuator, sensor and communication systems, imitating the energy sustenance mechanisms of natural organisms. [2].

The biomimetic design of artificial muscles, including those comprised of electroactive polymers (EAPs), resembles the soft physical structure of muscular organisms. These materials can respond with greater compliance to varied and unpredictable environments and have excellent thermodynamic efficiencies and low mass to power ratios compared to conventional electromechanical actuators [3]. Among the EAP technologies, IPMCs have been implemented in a number of applications including propulsion [4], stirring and cilia-like motion [5]. IPMCs are capable of significant actuation at low voltages (ca. 1-3V) due to induced ionic migration within the polymer layer when a potential is applied to the two noble metal electrodes.

In this work we demonstrate how an MFC 'stomach' can directly drive IPMC actuator 'muscles' though a low resistance switching circuit.

N.F. Lepora et al. (Eds.): Living Machines 2013, LNAI 8064, pp. 424–426, 2013.

2 Method and Results

2.1 Energy Harvesting from Sub-millilitre Scale MFC

The performance of two replicated systems, each comprising an MFC, charging two 1F super-capacitors in parallel (Fig.1a), was measured using a Pico Technology ADC-24 data logger. The capacitors were charged to a mean voltage of 475.4mV. Charging was terminated on day 6, after which negligible voltage increase was observed. The MFC (Fig.1a) anode chamber held 0.2mL of anolyte, and was open on one side, where a cation selective membrane (VWR, UK) of 15mm diam. was attached. A moistened, open to air cathode, was fitted against the exterior side of this membrane. Anode and cathode electrodes were made from carbon fibre veil, with surface areas of 1800mm² and 4500mm², respectively. The anolyte was sewage sludge mixed with tryptone (10%) and yeast extract (5%).

2.2 Actuation of IPMC Artificial Muscle

Two capacitors, charged from the output of a single MFC, were connected in series and discharged to a hydrated 2 x 1cm IPMC rectangular cantilever strip, actuated in free air (Fig.1b). The polarity of the applied voltage was switched, using an externally powered relay stage, with a frequency of 1Hz. Voltage across the IPMC was measured using a National Instruments PCI-6229 board. Actuation displacement was recorded using a Keyence laser sensor. The IPMC sample was fabricated from Nafion 112 (DuPont), coated with gold electrodes using electroless plating.

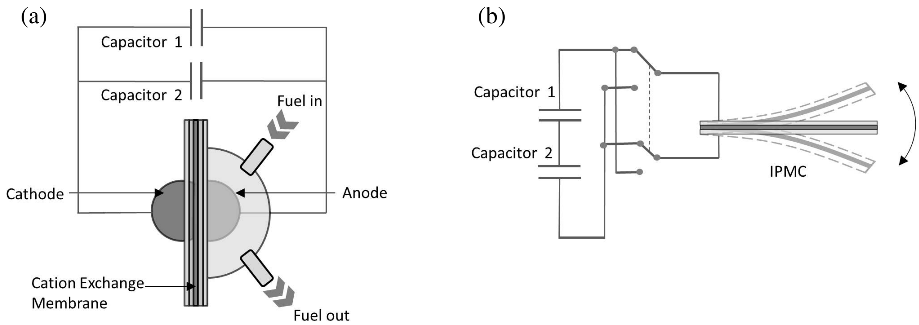

Fig. 1. Schematic of system configurations for **(a)** energy harvesting and **(b)** IPMC actuation

A clear actuation response to the applied voltage is shown by the IPMC artificial muscle (Fig.2). Voltage decay from 890mV to 282mV was accompanied by a decrease in amplitude of displacement from 0.2mm to 0.13mm per stroke over 60 actuations. Energy stored by the IPMC per actuation was calculated using Equation 1.

$$E = \frac{1}{2}CV_{final}^2 - \frac{1}{2}CV_{initial}^2 \quad (1)$$

where V_{final} and $V_{initial}$ are the respective final and initial voltages across the IPMC per stroke and C is the capacitance of the IPMC. The average decrease in energy per actuation stroke was only 3%, indicating the feasibility of multiple oscillations from a single capacitive charge supply.

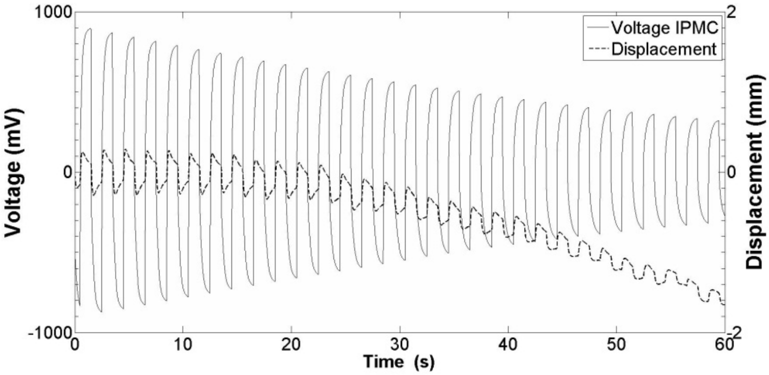

Fig. 2. IPMC displacement over 60s, driven directly from alternating supply charge, at 890mV

3 Summary

We have demonstrated the ability of a sub-mL MFC-powered system for sustained undulating soft-robotic actuation. The system achieved 60 actuations over a 1 minute interval from one capacitor charge cycle of 890mV. Potential uses for this low power generation and actuation mechanism include propulsion in a mobile robot and stirring in an MFC anode chamber. Further optimisation of the low-power switching mechanisms will lead to more effective power delivery to the IPMC actuator.

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