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Physical and chemical awareness from sensing polymeric artificial muscles. Experiments and modeling

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A B S T R A C T

Engineers, scientists and designers have been dreaming for decades of artificial motors sensing by themselves both surrounding and internal conditions, mimicking the proprioception, or consciousness of human beings. Here we review the state of the art of macroscopic artificial muscles based on electrochemical reactions, which drive conformational (basic molecular motors) and macroscopic (swelling/shrinking) movements in conducting polymers, sensing simultaneously mechanical, thermal or chemical perturbations. One reaction drives one motor and several sensors working simultaneously in one physically uniform device with two connecting wires that include both, actuating (current) and sensing (potential or consumed energy) magnitudes. The artificial system computer-generator/wires/muscle mimics the brain/nerves/muscles feedback communication and control. A multifunctional equation, based on electrochemical, mechanical and polymeric principles, quantifies the empirical simultaneous sensing-actuation describing artificial proprioception or awareness. Scientific and technological challenges are presented. Biomimetic polymeric reactions drive multifunctional properties, tools and devices. The theoretical description explains and quantifies aspects of an emerging artificial consciousness.

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1. Introduction

In the 50s of the past century Katchalsky realized that a film of a polymer gel located between two metallic electrodes inside an electrolyte bends in opposite directions when submitted to opposed electric fields [1]. In the context of polymeric materials, the name artificial muscles was initially assigned to those devices including gel films responding to electric pulses mediating some chemical reaction involving polymeric chains as reactants [2], or ionic and aqueous exchanges with the electrolyte [3–5], or all those processes taking place simultaneously in a reactive dense gel electrode immersed in an electrolyte [6]. From the beginning of the 90s it has been discovered that polymeric films can respond to a plethora of physical or chemical stimuli (light [7], temperature [8], magnetic fields [9], electric fields [10–12], electric currents [13], and so on) developing mechanical work. Most of those polymeric actuators have been named artificial muscles. Those transforming electrical energy into mechanical energy are some of the most studied polymeric electrical, electromechanical, electroactive, electrochemical or electrochemomechanical polymeric actuators or artificial muscles.

1.1. Electromechanical muscles

Most of the named polymeric artificial muscles are physical devices responding to electric fields, E (V), (electroactive or electromechanical) through different physical interactions: electrostrictive, piezoelectric, ferroelectric, coulombic (including ions), electrophoretic and electroosmotic (including ions and solvent) [2–5,7–12]. Most of those actuators alternatively behave as sensors [10]. Two physically separated independent devices with independent connecting wires constitute some of the claimed sensing-actuators [14].

1.2. Electro-chemo-mechanical muscles

Different polymeric families transform electrical energy into mechanical energy through electrochemical reactions, also named doping and de-doping processes [13,15–21]. They constitute chemical polymeric motors that respond to the flowing current, i (A), or to the consumed charge, q (C): Faradaic motors. They act alternatively [22–24], or simultaneously [25–27], as sensors of the working temperature, chemical ambient and trailed masses or mechanical perturbations. They are electro-chemo-mechanical devices: a flow of electrons promotes a chemical reaction, changing the composition (doping state) of the material and its volume (mechanical effect). Tactile muscles have been empirically developed providing information about either the presence of obstacles in its way, the energy required to shift the obstacle or if the muscle can or cannot displace it [26]. The driving reaction includes reactive polymeric chains, ions and water: the material is a dense reactive gel mimicking, in its simplest expression, the intracellular matrix (ICM) of living cells [28].

Here we will review the state of the art of those polymeric and multifunctional sensing-motors, which mechanical consistence is kept during the driving reactions, altogether those theoretical models (based on electrochemical, mechanical and polymeric principles) describing the incipient artificial proprioception. New challenges related to the possibility to produce more intelligent robots and to describe behavioral and psychological concepts as proprioception or consciousness by physico-chemical equations will be presented.