Electroactive Polymer (EAP) Actuators as Artificial Muscles

Reality, Potential, and Challenges

SECOND EDITION

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Editor

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Contents

Preface

This book reviews the state of the art of the field of electroactive polymers (EAPs), which are also known as artificial muscles for their functional similarity to natural muscles. This book covers EAP from all its key aspects, i.e., its full infrastructure, including the available materials, analytical models, processing techniques, and characterization methods. This book is intended to serve as reference tool, a technology users' guide, and a tutorial resource, and to create a vision for the field's future direction. In preparing this second edition, efforts were made to update the chapters with topics that have sustained major advances since the first edition was prepared three years ago. Following the reported progress and milestones that were reached in this field has been quite heartwarming. These advances are bringing the field significantly closer to the point where engineers consider EAPs to be actuators of choice. In December 2002, the Japanese company Eamex produced a robot fish that swims in a water tank without batteries or a motor. For power, the robot fish uses an inductive coil that is energized from the top and bottom of the tank. Making a floating robot fish may not be an exciting event, but this is the first commercial product to use an EAP actuator.

EAPs are plastic materials that change shape and size when given some voltage or current. They always had enormous potential, but only now is this potential starting to materialize. Advances reported in this second edition include an improved understanding of these materials' behavior, better analytical modeling, as well as more effective characterization, processing, and fabrication techniques. The advances were not only marked with the first commercial product; there has also been the announcement by the SRI International scientists who are confident they have reached the point that they can now meet the challenge posed by this book's editor of building a robot arm with artificial muscles that could win an arm wrestling match against a human. This match may occur in the coming years, and the success of a robot against a human opponent will lead to a new era in both making realistic biomimetic robots and implementing engineering designs that are currently considered science fiction.

For many years the field of EAP has received relatively little attention because the number of available materials and their actuation capability were limited. The change in this view occurred in the early 1990s, as a result of the development of new EAP materials that exhibit a large displacement in response to electrical stimulation. This characteristic is a valuable attribute, which enabled myriad potential applications, and it has evolved to offer operational similarity to biological muscles. The similarity includes resilient, damage tolerant, and large actuation strains (stretching, contracting, or bending). Therefore, it is natural to consider EAP materials for applications that require actuators to drive biologically inspired mechanisms of manipulation, and mobility. However, before these materials can be applied as actuators of practical devices their actuation force and robustness will need to be increased significantly from the levels that are currently exhibited by the available materials. On the positive side, there has already been a series of reported successes in demonstrating miniature manipulation devices, including a catheter steering element, robotic arm, gripper, loudspeaker, active diaphragm, dust-wiper, and many others. The editor is hoping that the information documented in this book will continue to stimulate the development of niche applications for EAP and the emergence of related commercial devices. Such applications are anticipated to promote EAP materials to become actuators of choice in spite of the technology challenges and limitations they present.

Chapter 1 of this book provides an overview and background to the various EAP materials and their potential. Since biological muscles are used as a model for the development of EAP actuators, Chapter 2 describes the mechanism of muscles operation and their behavior as actuators. Chapter 3 covers the leading EAP materials and the principles that are responsible for their electroactivity. Chapter 4 covers such fundamental topics as computational chemistry and nonlinear electromechanical analysis to predict their behavior, as well as a design guide for the application of an example EAP material. Modeling the behavior of EAP materials requires the use of complex analytical tools, which is one of the major challenges to the design and control of related mechanisms and devices. The efforts currently underway to model their nonlinear electromechanical behavior and develop novel experimental techniques to measure and characterize EAP material properties are discussed in Chapter 6. Such efforts are leading to a better understanding of the origin of the electroactivity of various EAP materials, which, in turn, can help improve and possibly optimize their performance. Chapter 5 examines the processing methods of fabricating, shaping, electroding, and integrating techniques for the production of fibers, films, and other shapes of EAP actuators. Generally, EAP actuators are highly agile, lightweight, low power, mass producible, inexpensive, and possess an inherent capability to host embedded sensors and microelectromechanical systems (MEMS). Their many unique characteristics can make them a valuable alternative to current actuators such as electroactive ceramics and shape memory alloys. The making of miniature insectlike robots that can crawl, swim and/or fly may become a reality as this technology evolves as discussed in Chapters 7 and 8. Processing techniques, such as ink-jet printing, may potentially be employed to make complete devices that are driven by EAP actuators. A device may be fully produced in 3D detail, thereby allowing rapid prototyping and subsequent mass production possibilities. Thus, polymer-based EAP-actuated devices may be fully produced by an ink-jet printing process enabling the rapid implementation of science-fiction ideas (e.g., insectlike robots that become remotely operational as soon as they emerge from the production line) into engineering models and commercial products. Potential beneficiaries of EAP capabilities include commercial, medical, space, and military that can impact our life greatly.

In order to exploit the greatest benefit that EAP materials can offer, researchers worldwide are now exploring the various aspects of this field. The effort is multidisciplinary and cooperation among scientists, engineers, and other experts (e.g., medical doctors) are underway. Experts in chemistry, materials science, electro-mechanics, robotics, computer science, electronics, and others are working together to develop improved EAP materials, processing techniques, and applications. Methods of effective control are addressing the unique and challenging aspects of EAP actuators. EAP materials have a significant potential to improving our lives. If EAP materials can be developed to the level that they can compete with natural muscles, drive prosthetics, serve as artificial muscle implants into a human body, and become actuators of various commercial products, the developers of EAP would make tremendously positive impact in many aspects of human life.

Yoseph Bar-Cohen
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