Bioinspired Actuators and Sensors

From authors renowned in the fields of engineering and biology, this is the first book to integrate sensor and actuator technology with bioinspired design.

Beginning with detailed descriptions of actuation and sensing mechanisms in plants and animals, the authors move on to apply these principles to synthetic design, offering in-depth knowledge of the development of state-of-the-art smart materials and devices. All of this is supported with a range of real-world applications, from tactile sensory systems in insects linked with the development of robotic hands, to the structural color systems in nature used to inspire camouflage technology. Further examples are given of successful designs along with their integrated autonomous systems, such as flying and swimming unmanned systems, and autonomous zero-energy building design.

With a wide interdisciplinary appeal, this is an ideal resource for any student, practicing engineer, or researcher interested in the connection between natural systems and synthetic design.

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Contents

Preface

This book is about ideas. Rather than painting human ingenuity as the product of esoteric human minds, here we examine the role of nature in inspiring great ideas. During millions of years of evolution biological species developed sensing and motor capabilities that went far beyond the abilities and imaginations of our own species. Only after having reached the technological and scientific level to detect electrical fields, ultrasound and infra-sound, infrared and ultraviolet radiation, only after having engineered our own devices for sonar and radar localization and infra-red vision, did we realize that similar systems were long in use by other species? Examples are the operation of ultrasound-based sonar location by whales, bats and sonar detection systems by moths, the still mysterious ultrasound long-distance communication in elephants and whales, the location by alterations in electric fields used by electric fishes, the magnetic fields and lunar cycles by plants, and the infra-red detection of neighbors by snakes, *Melanophila* beetles (Buprestidae), and plants. Aside from having such exceptional sensors, all biological beings integrate sensing and motor activity to adapt to changing conditions in a smart and autonomous way that characterizes life. Human-made sensors and actuators increasingly try to simulate this smart behavior through use of new, so-called smart materials which are discussed in Chapters 4 and 5 of this book. The present book reviews the sensing, cognitive, and motor activity of selected biological species and compares these with the level of smart materials designed by human engineering where we focus on insects as representative of the animal kingdom and action plants as representatives of active plant systems, although other species of plants and animals are also discussed as far as their behaviors are related to the main theme, "active and sensing mechanisms."

The motivation for writing this book stems from our own experience of a fruitful cooperation between engineering and biology. As engineers we were often lacking new ideas in our search for new design concepts that could be overcome by reviewing selected biological systems and mechanisms. Biologists, on the other hand, learn to understand their systems better by considering the intricacies of parallel man-made solutions. Finally, it is fun and exciting to learn more about the sophistication of nature that surrounds us and reminds us not to irreversibly destroy systems that still have so much to teach and give to this and future generations. We (Taya and Van Volkenburgh, University of Washington [UW]) started to discuss mechanisms inherent in action plant behavior back in 1998, and thereafter collaborated on a number of projects, papers, and reviews. Since the UW team can cover sensing and active mechanism of plants, but it

lacks the expertise of the sensing and active mechanisms of the animal kingdom, the UW team asked two entomologists, Nomura (insect wings, and their evolution) and Mizunami (microbrains of insects). Initially we thought that it would be nearly impossible for us to write such a book together, particularly because of the large gap between our disciplines of biology (Van Volkenburgh, Nomura, and Mizunami) and engineering of mechanics and materials (Taya). During the course of writing this book, we realize that this gap is artificial and needs to be overcome. It is artificial since nature does not bother about the human convenience of subdividing its actions into biological, chemical, physical, and engineering aspects. What has kept us moving in this direction is a strong common interest and curiosity centered on biological systems of sensing and actuation. Van Volkenburgh has been working on mechanisms of sensing and actuation of selected plants, while Nomura has been working on insect taxonomy, with emphasis on insect wings, and Mizunami has been studying the microbrains of insects. Taya has been working on design of synthetic active and sensing materials and their integrated devices. This book, written by the above four (plant biologist, two entomologists, and engineer), will cover biological sensing and active mechanisms, and design of human-made sensors and actuators.

It is noted that a good number of books recently have been published in the area of biomimetics, reflecting the very high attraction among researchers on related subjects. This book attempts a more cohesive view that integrates, evaluates, and compares natural and human-made solutions centered on sensing and active materials and their integrated systems. The book is composed of seven chapters. After an introduction (Chapter 1) that describes the appearance and role of bioinspiration in the course of human development, Chapter 2 gives an overview of particular principles of how biological species (both plant and animal kingdoms) are organized and constructed, where we focus mainly on insects to represent the animal kingdom. Chapter 3 gives a wide variety of examples of biological sensors and movement systems including photosynthesis of plants and bacteria, while Chapter 4 states a number of synthetic materials for use as sensing materials and sensors and Chapter 5 covers active materials and actuators, where color-changing semi-conductor materials are also discussed. Chapter 6 explores and explains the new bioinspired concepts of sensors and actuators, where some of them are transferred successfully to useful real applications. Chapter 7 discusses several examples of autonomous systems composed of these bioinspired sensors and actuators into autonomously adaptable, smart human-made structures, which simulate the very essence of living systems.

The book is a first attempt to provide fundamental knowledge of sensors and actuators in both biological and bio-inspired human-made designs for undergraduate seniors and graduate students, and engineers working in Research & Development programs that deal with sensors and actuators or with the development of autonomous systems. The authors' intention is to write the book in a clear and simple language that is easily understood by readers from both the biological and engineering sciences. Accordingly, the book is suited for anybody interested in human and natural creativity, anybody who wants an engineering view on some of the most interesting systems of the natural world. For the same reasons we think that the book can be easily adopted for

courses in biomimetics and bioinspired designs at universities and similar institutions. And finally, we hope in particular that it will be enjoyed by anybody who falls outside established categories; the reader we wrote this book for. After all, humans have been using biological species for their immediate necessity, food, and energy. After reading this book, the authors wish that readers are all convinced that Nature is not to be consumed, but kept as she is, so that we will be able to obtain lots of new ideas and concepts from Nature.

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recently passed away last summer (2014), which was quite a loss to the active materials research community.

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