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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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 impos-
sible 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, chem-
ical, 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.
M. Taya would like to extend his appreciations to the past and current students and researchers in the research areas covered in this book: Dr. Robert Liang of University of Washington, the late Professor William Armstrong of University of Wyoming, Prof. Tsutomu Mori of Tokyo Institute of Technology, Prof. Taishi Wade of Yokohama National University, and Prof. Hiroyuki Kato of Hokkaido University, Professor Testuo Tagawa of Nagoya University, both Prof. Rysuzo Watanabe and Prof. Youji Sutou of Tohoku University, Prof. Masahiro Kusaka of Hyougo Prefecture University, Prof. Jon Keon Lee of Catholic University of Korea, Prof. Onur C. Namli of Yeditepe University, Turkey for their contributions to the design of a number of shape memory alloys (SMA), ferromagnetic SMA (FSMA) materials, and their actuators. Among these past researchers, Prof. Mori deserves special recognition as he helped in modeling the structure–property relationships of a number of SMA and FSMA systems. Taya’s great appreciation goes to the former graduate students and post doctors: Prof. Martin Dunn of University of Colorado, Prof. Abdul Almajid of King-Saud University, Saudi Arabia, Prof. Jingfeng Li of Tsingha University, China, for their contributions to designs of piezoelectric ceramics based actuators, Prof. Hirohisa Tamagawa of Gifu University, Prof. Soo Yeun Kim of University of Washington, Dr. Jin Wang of Imergy Power, and Dr. Marie Le Guilly of Intel, and Dr. Suzana Popovic for their contributions to design of electroactive polymers and their sensors and actuators. Professor Michihiro Natori of JAXA deserves special recognition for his constant help in providing his valuable photos and data of space-deployable structures and also biological species. Taya is also thankful to those recent graduate students for their help in drawing figures and searching references: Dr. Hee Seok Kim of University of Houston, Mr. Hiromi Yasuda, Mr. Kevin Kadooka, Ms. Cheng Xu, and Ms. Nishita Anandan of University of Washington. Taya is very thankful to Mr. John Verzemnieks of Nabtesco for his efforts in proofreading Chapter 5 and also to Mr. Ken Taya who provided us with the cover design of the book.

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