Editorial
Special Issue on Biomimetic Sensors

BIOINSPIRATION, biomimetics, and bioreplication are three words that have entered the engineering lexicon during the last decade. Bioinspired engineering can be broadly defined as the production of a natural outcome of a biological activity: e.g., the concept of flying machines was inspired by the flight of birds. Biomimetic engineering is the reproduction of a natural functionality by copying certain physical and chemical attributes of an organism, as exemplified via a comparison of Velcro with burrs produced by certain plants. Bioreplication, the reproduction of natural devices, is nowadays emerging as, for instance, certain researchers seek to reproduce structural colors by directly replicating the iridescent wings of butterflies. All three are loosely grouped together as *biomimetics*.

In a broad sense, biomimetics implements ideas harvested from nature in different technoscientific disciplines, and is receiving attention due to major technological advances that allow us to approach the sophistication of biological systems. Biomimetics is highly multidisciplinary, embracing physics, materials science, biology, chemistry, mechanics, computing and control, design integration, optimization, multifunctionality, and cost effectiveness.

The aim of this Special Issue is to provide a snapshot of current research activities in the field of biomimetic sensors.

Mimicking cholesteric liquid crystals that were originally of botanical provenance, the optical response characteristics of sculptured thin films can be tuned through their morphology and porosity and by proper selection of the raw materials. Infiltration of the pores by an analyte changes the conditions for launching surface-plasmon-polarition waves, thereby furnishing an optical sensing scheme. This scheme is theoretically formulated by Mackay and Lakhtakia in their paper entitled "Modeling Chiral Sculptured Thin Films as Platforms for Surface-Plasmonic-Polaritonic Optical Sensing."

Some beetles and certain flat bugs can detect fires and of hot surfaces. Hair mechanoreceptors on the cuticle have evolved into infrared sensors. A microfluidic model of these photomechanical sensors is presented in the paper entitled "Biomimetic Infrared Sensors Based on Photomechanic Infrared Receptors in Pyrophilous ("Fire-Loving") Insects," by Schmitz, Soltner, and Bousack.

The visual system of the common housefly has inspired the design of different sensors which are discussed in this Special Issue. Each eye of the housefly is an array of a multitude of eyelets, each of which individually forms a poor image; functioning in parallel, however, the eyelets provide a very wide field of vision and can detect object motion much finer than their spacing suggests. The apposition compound eye is emulated by sensors mounted in unmanned aerial vehicles for obstacle avoidance, landing support, and target tracking In this regard, a paper entitled "Biomimetic Attitude and Orientation Sensors" and coauthored by Chahl and Mizutani, is focused on two biomimetic sensors that use the spectral, spatial, and polarization distributions of light in the environment for aerial navigation and aircraft stabilization. The first sensor is a sky polarization compass that many insects have for navigation, the second is based on the optical stabilization organs of dragonflies. Both should be useful for autopiloting small unmanned aerial vehicles.

The common housefly has inspired vision sensors to detect small moving objects at various speeds and levels of contrast. The performance of these sensors is shown to be superior to that of a CCD camera sensor by Prabhakara, Wright, and Barrett, in their paper entitled "Motion Detection: A Biomimetic Vision Sensor Versus a CCD Camera Sensor." The superiority is particularly noticeable for complex motion and in low-contrast conditions. Luke, Wright, and Barrett, in their paper entitled "A Multiaperture Bioinspired Sensor With Hyperacuity," show that motion hyperacuity of compound eyes can be achieved through a controlled preblurring of an optical imaging system, and their theoretical analysis promises a threefold improvement in signal-to-noise ratio and motion acuity.

Ocular tremor found in many vertebrate and invertebrate animals has inspired the development of an optical sensor for accurate positioning applications. The front end of the sensor consists of a pair of photoreceptors that translate repetitively on the microscale. Details of the design and fabrication of such devices are described by Kerhuel, Viollet, and Franceschini in "The VODKA Sensor: A Bio-Inspired Hyperacute Optical Position Sensing Device."

The paper entitled "A Biomimetic Active Electrolocation Sensor for Detection of Atherosclerotic Lesions in Blood Vessels," coauthored by Metzen, Biswas, Bousack, Gottwald, Mayekar, and von der Emde, deals with the fabrication of catheter-based technical sensor systems inspired in the capacity of deep-sea fish to sense their surroundings in complete darkness using weak electric fields. These biomimetic sensors make use of the same principle and may help in diagnosing arteriosclerosis.

Finally, three papers in this Special Issue focus on the development of biomimetic tactile sensing systems based on the facial whiskers of such animals as rats and mice. Possessing an elaborate morphology, whiskers are exquisite mechanoreceptors, as explained by Carl, Klauer, Schilling, Voges, and Witte in

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their paper entitled "Structural Characterization of the Whisker System of the Rat," and by Carl, Hild, Mämpel, Schilling, Uhlig, and Witte in their paper entitled "Characterization of Static Properties of Rat's Whisker System." A conical array of modulated hair-like elements, with a feedback mechanism, has been designed, fabricated, and tested by Sullivan, Mitchinson, Pearson, Evans, Lepora, Fox, Melhuish, and Prescott in their paper entitled "Tactile Discrimination using Active Whisker Sensors." Active vibrissal sensing would be useful for deployment in autonomous robots.

Plants, insects, rodents, and fish—all have inspired technoscientists to come up with new ways of sensing environmental variables and nearby objects. We are confident that the 12 papers included in this Special Issue will firm up both the foundations of and technoscientific interest in biomimetic sensors.

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Raúl J. Martín-Palma received the M.S. degree in applied physics and the Ph.D. degree in physics from the Universidad Autónoma de Madrid, Spain, in 1995 and 2000, respectively.

He is a Professor of Physics at the Department of Applied Physics, Universidad Autónoma de Madrid, and Adjunct Professor at the Department of Materials Science and Engineering, Pennsylvania State University, University Park. He has been a Postdoctoral Fellow at the New Jersey Institute of Technology (Newark, NJ) and Visiting Professor at the Pennsylvania State University. He is an Associate Editor of the *Journal of Nanophotonics* published by SPIE. He is the author or coauthor of over 100 research papers in peer-reviewed journals, and has coauthored two books in the field of nanoscience and nanotechnology.

Dr. Martín-Palma has received several awards for young scientists for his research on nanostructured materials from the Materials Research Society (USA), the European Materials Research Society, and the Spanish Society of Materials.

Akhlesh Lakhtakia was born in Lucknow, India, on July 1, 1957. He received the Bachelor of Technology degree in electronics engineering from the Banaras Hindu University, Varanasi, India, in 1979, the M.Sc. and Doctor of Philosophy degrees in electrical engineering from the University of Utah, Salt Lake City, in 1981 and 1983, respectively, and the Doctor of Science degree in electronics engineering from the Banaras Hindu University in 2006.

Thereafter, he joined the faculty of the Pennsylvania State University, University, Park, where he was elevated to the rank of Distinguished Professor of Engineering Science and Mechanics in January 2004. In 2006, he became the Charles Godfrey Binder (Endowed) Professor of Engineering Science and Mechanics. He also serves as a Professor in the Graduate Programs in Materials and Forensic Science. From 2004 to 2007, he also held the rank of a Visiting Professor of Physics at Imperial College, London. He has published more than 690 journal articles, has contributed 19 chapters to research books and encyclopedias, has edited, coedited, authored or coauthored 16 books and 10 conference proceedings, and has reviewed for 113 journals. He serves on the editorial boards of four electromagnetics journals, was the Editor-in-Chief of the international journal *Speculations in Science and Technology* from 1993 to 1995, and became the first Editor-in-Chief of the online *Journal of Nanophotonics* published by SPIE since 2007. He served as an International Lecturer for the International Commission for Optics and the Optical Society of America, was twice a Visiting Professor of Physics at the Universidad de Buenos Aires, a Visiting Professor of Physics at the University of Otago, and a Visiting Fellow in Mathematics at the University of Glasgow. He also served as the 1995 Scottish Amicable Visiting Lecturer at the University of Glasgow. His current research interests lie in the electromagnetics of complex materials, sculptured thin films, chiral nanotubes, nanoengineered metamaterials, biomimetics, and surface multiplasmonics. At Pennsylvania State University, he co-developed a course on green engineering for undergraduate engineering students, as well as a course on fundamentals of engineering principles and design for preservice elementary schoolteachers.

Dr. Lakhtakia headed the IEEE EMC Technical Committee on Nonsinusoidal Fields from 1992 to 1994, is a Fellow of the Optical Society of America, SPIE, the American Association for the Advancement of Sciences, and the Institute of Physics (U.K.). He received the PSES Outstanding Research Award in 1996, the PSES Premier Research Award in 2008, and the PSES Outstanding Advising Award in 2005. For his research on sculptured thin films and complex-medium electromagnetics, he received the Faculty Scholar Medal in Engineering in 2005 from the Pennsylvania State University and the 2010 SPIE Technical Achievement Award. Nanotech Briefs recognized him in 2006 with a Nano 50 Award for Innovation. The University of Utah made him a Distinguished Alumnus in 2007.