

CONTENTS

Preface	vii
About the Editors	xxiii
About the Contributors	xxvii
17. Bioinspired Design of Peripheral Nerve Devices	419
<i>Sameer B. Shah</i>	
1. Introduction and Scope	419
2. Architecture and Biomechanics of the Peripheral Nervous System	420
2.1. Anatomy and ultrastructure of the peripheral nervous system	420
2.2. Biomechanics of the peripheral nervous system	422
3. Peripheral Nerve Devices in Clinical Use or Under Development	425
3.1. Sacral nerve stimulation	425
3.2. Vagus nerve stimulation	426
3.3. Phrenic nerve stimulation	428
3.4. Occipital and trigeminal nerve stimulation	429
3.5. Peripheral nerve stimulation for enhanced sensory-motor function	430
3.6. Non-contact strategies	432
4. Conclusions	433
Acknowledgments	434
References	434

18. Bioinspired Artificial Muscles and Robots	443
<i>Il-Kwon Oh and Choonghee Jo</i>	
1. Introduction	443
2. Electro-active Polymer Actuators	444
2.1. Characteristics and actuation types of EAP	444
2.2. Actuation behaviors	446
2.3. Adaptability of EAP actuators for biomedical devices	448
2.4. New type of IPMC	449
3. Application	455
3.1. Biomimetic robots	455
3.1.1. Underwater micro-robot	455
3.1.2. Biomimetic fish-like EAP robot	456
3.2. Biomedical devices	463
3.2.1. Electro-active polymers	463
3.2.2. Applications	465
4. Conclusions and Outlook	471
References	471
19. Biomimetic Materials and Multivariate Approach to Odor Sensing	475
<i>Takamichi Nakamoto and Bartosz Wyszynski</i>	
1. Introduction	475
2. Principle of Artificial Olfaction	476
3. Biomimetic and Bioinspired Materials for Odor Sensing	478
3.1. Lipids and lipid-derivatives for odor sensing	480
3.2. Bioinspired materials for odor sensing	488
3.3. Biological materials for odor sensing	489
4. System for Outputting Biomimetic Sensory Quantities	492
4.1. Mapping of mass spectrum into sensory quantity	492
4.1.1. Mass spectrometry	492
4.1.2. SOM neural network	493
4.1.3. Experiment	493
4.1.4. Result	494
4.2. Odor recorder	495
4.2.1. Background of odor recorder	495
4.2.2. Odor recorder based upon active sensing	497
4.2.3. MIMO feedback for obtaining static recipe	498
4.2.3.1. Two-level quantization method	498
4.2.3.2. Singular value decomposition method	500
4.3. Odor approximation	501

5. Conclusions and Outlook	504
Acknowledgments	504
References	504
20. Biomimetic Cilia	509
<i>Jae-Hyun Chung, Tae-Rin Lee and Wing Kam Liu</i>	
1. Introduction	509
2. Working Principles of Biomimetic Cilia	511
2.1. Sperm number	511
2.2. Added mass effect for resonance of cilia	511
3. Numerical Methods	512
3.1. Immersed boundary method	512
3.2. Diffusion-advection-reaction equation solver	514
3.3. Hybrid lattice-boltzmann and lattice-spring method	515
4. Fabrication and Actuation	517
4.1. Design and fabrication of highly compliant cilia structures	518
4.1.1. Magnetic field induced actuation	519
4.1.2. Biomorph actuator	520
4.1.3. Vibration-induced actuation of cilia	520
4.1.4. Other actuation methods	524
5. Applications	524
5.1. Microfluidic — pump and mixer	524
5.2. Bioreactors	528
6. Conclusions and Outlook	530
Acknowledgments	530
References	531
21. Infrared Sensors Inspired by Pyrophilous Insects	533
<i>Herbert Bousack, Helmut Soltner, David Klocke and Helmut Schmitz</i>	
1. Introduction	533
2. Structure and Function of the Photomechanic Receptor in Pyrophilous Insects	535
2.1. Receptor structure	535
2.2. Receptor function	538
3. Sensitivity of Pyrophilous Beetles for Fire Detection	539
4. Transfer of the Sensillum in a Technical Solution	545
4.1. Golay sensor	545

4.2.	Sensor model based on the photomechanic receptor	546
4.2.1.	Design Parameters	547
4.2.2.	Pressure increase of the cavity and membrane deflection without compensation leak	549
4.2.3.	Pressure increase of the cavity with compensation leak	552
4.3.	Experimental results	559
5.	First Devices	561
6.	Conclusions and Outlook	562
	Acknowledgments	562
	References	562
22.	Insect Inspired Visual Motion Sensing and Flying Robots	565
	<i>Thibaut Raharijaona, Lubin Kerhuel, Julien Serres, Frédéric Roubieu, Fabien Expert, Stéphane Viollet, Franck Ruffier and Nicolas Franceschini</i>	
1.	Introduction	566
2.	Recent Advances in the Topic	567
2.1.	Optic flow-based autopilots	567
2.2.	Hyperacuity and Bioinspired optical sensing	568*
2.3.	Gaze stabilization for aerial robots	570
3.	The Fly's Eye	572
4.	Insect-Based Visual Motion Sensors	574
4.1.	Description of the local visual motion sensors	575
5.	Optic-Flow Regulation for Guidance and Navigation	578
5.1.	The problem of ground avoidance	578
5.2.	The optic flow regulation principle	580
5.3.	A micro-helicopter equipped with an OF sensor and an OF regulator	581
5.4.	Micro-hovercraft against honeybees' behavioral patterns	582
6.	Insect-Based Active Vision for Hyperacute Position Sensing	586
6.1.	Principle of the hyperacute sensor	586
6.2.	Noteworthy features of the hyperacute sensor	590
6.2.1.	Robustness to lighting conditions	590
6.2.2.	Robustness to contrast value and contrast polarity	590
6.2.3.	Robustness to vibration types	590

7.	Bioinspired Gaze Control Strategies for Aerial Robots	591
7.1.	Eye-in-head or head-in-body movements: A key to forward visuomotor control	593
7.2.	Description of the OSCAR II robot	594
7.3.	Implementation of the robot's oculomotor system	596
7.4.	"Steering-by-gazing" control strategy	597
7.4.1.	Eye-Control strategy	598
7.4.2.	Heading Control Strategy	600
7.4.3.	Rejection of aerodynamic perturbations	600
8.	Conclusion	604
	Acknowledgments	605
	References	605
23.	Insect-Inspired Micro Air Vehicles	613
	<i>Rajeev Kumar, Ryan Randall, Dima Silin and Sergey V. Shkarayev</i>	
1.	Introduction	614
2.	Locusts	616
2.1.	General information	616
2.2.	Wings	617
3.	Ornithopters	618
3.1.	Design considerations	618
3.2.	Scaling and trends	619
3.3.	Material selection and fabrication techniques	620
4.	Experimentation	622
4.1.	Experimental subjects	622
4.2.	Experimental setup, apparatus and procedure	624
4.3.	Conventions for aerodynamic forces and kinematic parameters	626
5.	Results and Discussion	628
5.1.	Kinematics of locust hindwings	628
5.2.	Force measurements on artificial wings	630
5.2.1.	Effect of chordwise flexibility	630
5.2.2.	Effect of active pitching	631
6.	Ornithopter Design and Specifications	633
7.	Conclusion	636
	Acknowledgments	637
	References	638

24.	Microfabricated Auditory System Mimicking Human Cochlea	641
	<i>Hongsoo Choi, Jeong Hun Jang and Won Joon Song</i>	
1.	Introduction	642
2.	Physiology of the Cochlea and Hearing	642
2.1.	Anatomy and physiology of the cochlea	642
2.2.	Hearing mechanism in the cochlea	645
3.	Macroscale Model of the Passive Cochlear Mechanism	648
4.	Microscale Artificial Cochlea	655
5.	Conclusions and Outlook	665
	Acknowledgments	666
	References	666
25.	Olfactory and Geomagnetic Perception Inspired Bionic Sensing	669
	<i>Yahui Man, Weisong Pan, Yan Liu, Xianli Du and Wenjian Wu</i>	
1.	Introduction	669
2.	Vertebrate and Invertebrate Olfaction	672
2.1.	Vertebrate biological olfaction	672
2.2.	Invertebrate biological olfaction	673
2.2.1.	Olfaction sensing processes in insects	674
2.2.2.	Insect odorant receptors	675
3.	Electronic Nose Sensor Types	676
3.1.	Metal-oxide sensors	676
3.2.	Conducting or conductive polymer gas sensors	677
3.3.	Acoustic wave gas sensors	677
3.4.	Calorimetric or catalytic bead (CB)	678
3.5.	Optical sensor systems	678
4.	Bionic Noses	679
4.1.	Insect as an ideal model for olfactory studies	679
4.2.	Limitations in current bionic sensor technologies	681
4.3.	Outlook for bionic sensor technologies and future perspective	681
5.	Bionic Sensing Inspired from Animal Geomagnetic Perception	682
5.1.	Theory	684
5.2.	Candidate magnetoreceptor molecules: The cryptochromes	685
5.3.	Model compounds and sensor development	687
5.4.	Outlook for bionic geomagnetic perception and future perspective	688
	References	689

26. Owl Inspired Silent Flight	695
<i>Thomas Bachmann and Andrea Winzen</i>	
1. Introduction	695
1.1. Principles of flight	697
1.2. Anatomy of bird's wings	697
1.3. Anatomy of a feather	698
2. Anatomical Features of the Owls' Plumage and Wings	699
2.1. Serrations	701
2.2. Fringes	702
2.3. Velvety surface	704
2.4. Porosity of feathers	705
3. Experimental Findings of Physical Principles in Noise Reductions and Air Flow Control Used by Owls	705
3.1. Friction reduction and flight style	706
3.2. Transition control (velvet)	706
3.3. Transition control (serrations)	712
3.4. Smooth surface and antifruttering (fringes)	715
4. Conclusion and Outlook	715
Acknowledgment	716*
References	716
27. The Cochlea, Surface Acoustic Waves, and Resonance	719
<i>Andrew Bell</i>	
1. Introduction	719
2. Assembling the 'Cochlear Amplifier'	721
3. Overview of the Surface Acoustic Wave Model	722
4. Krauklis Wave Velocity: First Non-Adjustable Parameter	724
5. Distance Between OHC Rows: Second Non-Adjustable Parameter	727
6. Tilt of the Lattice Specifies Q: Third Non-Adjustable Parameter	728
7. Traveling Wave Velocity: Fourth Non-Adjustable Parameter	730
8. Towards a Resonance Theory of Hearing	732
9. The 'Smart' Cochlea	734
10. Conclusions and New Directions	737
Acknowledgments	740
References	740

28. Bioinspired Smart Nanochannels	743
<i>Wei Guo and Lei Jiang</i>	
1. Introduction	743
1.1. Solid-state nanopores	747
1.2. Biomimetic smart nanopores and their applications	748
2. Basic Concepts on Ion Transport in Nanofluidic Channels	750
2.1. Electric double layer	750
2.2. Electrokinetic effects in nanofluidic channels	751
2.2.1. Electro-osmosis	752
2.2.2. Electrophoresis	753
2.2.3. Streaming potential	753
2.2.4. Concentration polarization	754
2.3. Theoretical models	755
2.3.1. Continuum dynamics	755
2.3.2. Stochastic dynamics and molecular dynamics	757
2.4. Nanofluidic Devices	759
2.4.1. Nanofluidic diode and nanofluidic transistor	759
2.4.2. Energy conversion	760
3. Biomimetic Smart Nanopores and Nanochannels	765
3.1. Biological nanopores	765
3.2. Biomimetic solid-state nanopores	768
3.2.1. pH responsive nanopores	769
3.2.2. Temperature responsive nanopores	771
3.2.3. Light responsive nanopores	773
3.2.4. Electric potential responsive nanopores	774
3.2.5. Ions responsive nanopores	775
3.2.6. Molecular responsive nanopores	776
3.2.7. Multiple responsive smart nanopores	777
4. Conclusions and Outlook	779
Acknowledgments	780
References	780
29. Bioinspired Non-Imaging Optics	785
<i>Jaeyoun Kim</i>	
1. Introduction	785
2. Biological and Bioinspired Non-Imaging Light Sensors	786
2.1. Algal light antenna	786
2.2. Echinodermal eyes	790
2.3. Ocelli	793

3.	Biological and Bioinspired Non-Imaging Subsystems	795
3.1.	Polarization optics	796
3.2.	Light collection and concentration	799
4.	Engineering Perspectives of Biological Non-Imaging Optics	801
4.1.	Combined use of heterogeneous mechanisms	802
4.2.	Multiplicity in targeted functionalities	803
5.	Routes to Surpass Biological Non-Imaging Optics	803
5.1.	Incorporation of plasmonic effects	804
5.2.	Integration with optofluidic functionalities	806
5.3.	Exploiting wider range of materials and architectures	807
6.	Counter-Bioinspired Non-Imaging Optics	808
7.	Conclusion	812
	Acknowledgments	812
	References	812
30.	Biomimetic Multizone Temperature Control	817
	<i>Andrés Pantoja, Nicanor Quijano and Germán Obando</i>	
1.	Introduction	817
2.	Biological Model	822
2.1.	Standing-crop model	822*
2.2.	Replicator dynamics	823
2.3.	Population distribution with replicator dynamics in a habitat modeled by the standing-crop	824
2.3.1.	The standing-crop model with IFD	825
2.3.2.	Standing-crop and replicator dynamics	826
3.	Uniform Temperature Control of a Disjoint Multizone System	828
3.1.	Thermal model	828
3.2.	Control dynamics	829
3.2.1.	Equilibrium points for controlled system	830
3.3.	Stability analysis	832
3.3.1.	Indirect method of Lyapunov	833
3.3.2.	Sum of squares (SOS) techniques stability analysis	834
3.4.	Experimental multizone temperature control	838
3.5.	Discussion	843
4.	Set Point Temperature Control of a Coupled Multizone System	844
4.1.	Thermal model for interconnected zones	844
4.2.	Control dynamics	845
4.3.	Stability analysis	847

4.4.	Control performance under strong power limitation	848
4.5.	Simulation results	849
5.	Conclusions	852
	Acknowledgments	853
A.1	Appendix	853
A.1.1	Proof of Theorem 1	853
A.1.2	Proof of Theorem 2	856
	References	858
31.	Hair-Based Flow-Sensing Inspired by the Cricket Cercal System	861
	<i>G. J. M. Krijnen, H. Droogendijk, T. Steinmann, A. Dagamseh,</i> <i>R. K. Jaganatharaja and J. Casas</i>	
1	Introduction	861
2	Hair-Sensors	864
2.1	Flow as information source	864
2.2	Hair-sensor physics	864
2.3	Hair-sensor design	868
2.3.1	Hair length and boundary layer	868
2.3.2	Hair diameter and viscous drag	869
2.3.3	Torsional stiffness	869
2.3.4	Damping	869
2.3.5	Torsional spring material	870
2.3.6	Figure of Merit	870
2.3.7	Capacitive read-out	871
2.4	Optimization of hair geometry	872
2.4.1	Importance of hair shape	872
2.4.2	Artificial hairs: Past and present	872
2.4.3	Nature-like hairs: Future?	874
3	Viscous Coupling	875
4	Array-Sensing	876
4.1	Transient airflow measurements using artificial hair sensors	879
4.2	Measurements setup and results	879
5	Beyond Bio-Inspiration: Parametric Effects	882
5.1	DC-biasing	884
5.2	Parametric amplification	884
5.3	EMAM	885
6	Summary and Conclusions	885
	Acknowledgments	886
	References	886

32. Mechanics-Related Bioinspired Optimization	889
<i>Xiang Feng, Francis C. M. Lau and Huiqun Yu</i>	
1. Introduction	889
1.1. Long-term impact	889
1.2. Background of research	890
1.2.1. Bioinspired approaches	891
1.2.2. Physics-inspired approaches	891
1.2.3. Mechanics-related bioinspired approaches	892
2. Crossbar Composite Spring Net Algorithm	894
2.1. A problem model for MASSs	895
2.2. CCSN architecture	895
2.3. Evolution of the CCSN	897
2.3.1. Remarks	901
2.4. Proving the model	901
2.5. The parallel CCSN algorithm	905
2.6. Testing our approach	905
3. Conclusions	906
Acknowledgments	908
References	908
Index	II-1