Advanced Technologies for Brain Research

By Metin Akay, *Fellow IEEE*
Guest Editor

Paul Sajda, *Fellow IEEE*
Guest Editor

Silvestro Micera
Guest Editor

Jose M. Carmena, *Senior Member IEEE*
Guest Editor

We believe that this special issue will serve to increase the public awareness and foster discussions on the multiple worldwide BRAIN initiatives, both within and outside the IEEE, providing an impetus for development of long-term cost-effective healthcare solutions. We also believe that the topics presented in this special issue will serve as scientific evidence for health and policy advocates of the value of neurotechnologies for improving the neurological and mental health and wellbeing of the general population. Below we briefly highlight the papers and technologies in this special issue.

The first paper, "Silicon-Integrated High-Density Electrocortical Interfaces" by Ha *et al.*, examines the state of the art of chronically implantable electrocorticography (ECoG) interface systems, as part of the Brain Research through Advancing Innovative Neurotechnologies (BRAIN) Initiative, and introduces a novel modular ECoG system using an encapsulated neural interfacing acquisition chip (ENIAC) that allows for improved, broad coverage in an area of high spatiotemporal resolution.

The second paper, "Framework for the Development of Neuroprostheses: From Basic Understanding by Sciatic and Median Nerves Models to Bionic Legs and Hands" by Raspopovic *et al.*, focuses on a novel, less invasive or intrusive neural prosthesis design by optimizing the neural interface geometry and the number of stimulating contacts for any specific nerve. The results suggest that this type of stimulation could be used in humans for testing of afferent stimulation paradigms and could provide a procedure for reliable chronic implants.

The papers in this special issue highlight the development of a broad set of novel neurotechnologies for experimentally probing, stimulating, and mapping the structure and function of the brain and emphasize the clinical implications of these recent technological advances.

The third paper, "Stable Detection of Movement Intent From Peripheral Nerves: Chronic Study in Dogs" by Dweiri *et al.*, emphasizes the need for intuitive control of high-degree-of-freedom prosthetic limbs. It proposes a detection method for fascicular-level neural activity under freely moving conditions that avoids compromising the peripheral nerves by using flat interface nerve electrodes (FINEs). The results from this paper suggest that the incorporation of FINE into intuitively controlled advanced prostheses could produce more lifelike prosthesis control and enhance patient quality of life.

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The fourth paper, "A Nonhuman Primate Brain–Computer Typing Interface" by Nuyujukian *et al.*, discusses the feasibility of using brain–computer interfaces (BCIs) as communication interfaces for communication neural prostheses, and compares two high-performing BCI decoders in a typing task simulation. The results include reaching the highest known achieved communication rates using a BCI and determining the upper limit of achievable typing rate for a given BCI throughput.

The fifth paper, "Reliable Next-Generation Cortical Interfaces for Chronic Brain–Machine Interfaces and Neuroscience" by Maharbiz *et al.*, discusses recent advances in neurotechnology developed at the University of California Berkeley, including ultrasmall, ultracompliant implantable recording technology, as well as active devices which enable RF coupling, front-end amplification, and transcranial communication. The paper also postulates a vision for future neural interface systems, highlighting the key features that will provide the most significant advancements in neuroscience and neurology.

The sixth paper, "Fusing Multiple Neuroimaging Modalities to Assess Group Differences in Perception–Action Coupling" by Muraskin *et al.*, investigates brain behavior relationships using novel machine learning methodologies and neuroimaging technologies. Specifically, it shows the efficiency of multimodal neuroimaging technologies to identify structure and function of brain networks that clearly differentiate groups of subjects based on their level of expertise in a real-world rapid decision-making task.

The seventh paper, "Let There Be Light–Optoprobes for Neural Implants" by Alt *et al.*, provides an overview of optoprobe technology and its application to chronic neural implants. It also provides a previously undefined context of the state of the art of customized optoprobes for optical neural interfaces.

The eighth paper, "Advances in Two-Photon Scanning and Scanless Microscopy Technologies for Functional Neural Circuit Imaging" by Schultz *et al.*, provides an overview of recent advances in neural circuit imaging technologies, including the resulting technical challenges of signal processing and data analysis tools. It also discusses the requirement of scalable analysis tools to handle spatiotemporal or spatial neural activity patterns.

The ninth paper, "Implantable Microimaging Device for Observing Brain Activities of Rodents" by Ohta *et al.*, discusses three categories of implantable microimaging devices for observing small animal brain activity. It highlights the ultrasmall image sensor category for its ability to explore deep brain activity under freely moving conditions.

Challenges and Opportunities

The focus of the BRAIN Initiative is not only on technology *per se*, but also on the development and use of tools for acquiring fundamental insight about how the nervous system functions in health and disease, in other words, developing experimental and computational tools for integrating physiology, anatomy, and behavior. This will require developing technologies and experimental techniques that enable observation and perturbation of complete, functionally relevant neural circuits, including clearly defined input and output neurons, during behavior and learning, and scalable to large-scale neuronal networks across species. A challenge will be to take these experimental observations and use them, in conjunction with computational analysis and theory, to infer functional circuits that span multiple scales of the brain's organization. In addition to understanding the healthy and diseased brain, this fundamental knowledge of circuit function will be potentially crucial for developing a next generation of neuroprosthetic technologies to restore and/or enhance cognitive, motor, and sensory function, improving the quality of life of both the disabled and neurologically healthy populations, resulting in tremendous social and economic impacts. ■

ABOUT THE GUEST EDITORS

Metin Akay (Fellow, IEEE) is currently the founding chair of the new Biomedical Engineering Department and the John S. Dunn Professor of Biomedical Engineering at the University of Houston, Houston, TX, USA. His Neural Engineering and Informatics Lab is interested in developing an intelligent wearable system for monitoring motor functions in Post-Stroke Hemiplegic Patients and detecting coronary artery disease.

Dr. Akay is a recipient of the IEEE EMBS Early Career and Service awards as well an IEEE Third Millenium Medal. He is a Fellow of the Institute of Physics (IOP), the American Institute of Medical Biological Engineering (AIMBE), and the American Association for the Advancement of Science (AAAS). He is the founding Editor-in-Chief of the *Biomedical Engineering Book Series* published by Wiley/IEEE Press and the *Wiley Encyclopedia of Biomedical Engineering*. He is also the editor of the *Neural Engineering Handbook* published by Wiley/IEEE Press and the first steering committee chair of the IEEE TRANSACTIONS ON COMPUTATIONAL BIOLOGY AND BIOINFORMATICS. He established the IEEE Engineering in Medicine and Biology Society (EMBS) Special Topic Conference on Neural Engineering. He was also the first Chair of the IEEE EMBS Neuroengineering Technical Committee. He was the Program Chair of the International IEEE EMBS 2001, the Co-chair of the International IEEE EMBS 2006, and the Program Co-chair of the International IEEE EMBS 2011 and the IEEE EMBS Point-of-Care Health Technologies (POCHT) 2013. He currently serves on the advisory board of several international journals including the IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING, the IEEE TRANSACTIONS ON INFORMATION TECHNOLOGY IN BIOMEDICINE, *Smart Engineering Systems*, etc., and furthermore serves on several National Institutes of Health (NIH) and National Science Foundation (NSF) review panels.

Paul Sajda (Fellow, IEEE) is a Professor in the Departments of Biomedical Engineering, Electrical Engineering, and Radiology and Director of the Laboratory for Intelligent Imaging and Neural Computing, Columbia University, New York, NY, USA. Much of his current research focuses on using multimodal neuroimaging and behavioral measures to track selective attention and the dynamics of cognitive state during rapid decision making. He also applies these basic scientific findings to engineer neurotechnology systems that improve human–machine interaction.

Prof. Sajda is the Editor-in-Chief of the IEEE TRANSACTIONS ON NEURAL SYSTEMS AND REHABILITATION and Chair of the IEEE BRAIN Initiative.

Silvestro Micera received the University degree (Laurea) in electrical engineering from the University of Pisa, Pisa, Italy, in 1996 and the Ph.D. degree in biomedical engineering from the Scuola Superiore Sant'Anna (SSSA), Pisa, Italy, in 2000.

He is currently a Professor of Biomedical Engineering at SSSA and an Associate Professor of Biomedical Engineering at the Ecole Polytechnique Federale de Lausanne, Lausanne, Switzerland, where he is holding the Bertarelli Foundation Chair in Translational NeuroEngineering. From 2000 to 2009, he was an Assistant Professor of BioRobotics at the SSSA. In 2007, he was a Visiting Scientist at the Massachusetts Institute of Technology, Cambridge, MA, USA, with a Fulbright Scholarship. From 2008 to 2011, he was the Head of the Neuroprosthesis Control group and an Adjunct Assistant Professor at the Institute for Automation, Swiss Federal Institute of Technology, Zurich, Switzerland. He is the author of more than 100 ISI scientific papers and several international patents. His research interests include the development of neuroprostheses based on the use of implantable neural interfaces with the central and peripheral nervous systems to restore sensory and motor function in disable persons. In particular, he is currently involved in translational experiments for hand prosthesis control in amputees, and the restoration of vestibular function, grasping, and locomotion in different neurological disorders.

Dr. Micera is an Associate Editor of the IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING and the IEEE TRANSACTIONS ON NEURAL SYSTEMS AND REHABILITATION ENGINEERING. He is also a member of the Editorial Boards of *Journal of Neuroengineering and Rehabilitation*, *Journal of Neural Engineering*, and *IEEE Journal of Translational Engineering in Health and Medicine*. In 2009 he was the recipient of the "Early Career Achievement Award" of the IEEE Engineering in Medicine and Biology Society.

Jose M. Carmena (Senior Member, IEEE) received the B.S. degree in electrical engineering from the Polytechnic University of Valencia, Valencia, Spain, in 1995, the M.S. degree in electrical engineering from the University of Valencia, Valencia, Spain, in 1997, and the M.S. degree in artificial intelligence and the Ph.D. degree in robotics from the University of Edinburgh, Edinburgh, Scotland, U.K., in 1998 and 2002, respectively.

Currently, is the Chancellor's Professor in the Department of Electrical Engineering and Computer Sciences, and the Helen Wills Neuroscience Institute, University of California Berkeley, Berkeley, CA, USA and Co-Director of the Center for Neural Engineering and Prostheses at the University of California Berkeley and University of California San Francisco. His research program in neural engineering and systems neuroscience is aimed at understanding the neural basis of sensorimotor learning and control, and at building the science and engineering base that will allow the creation of reliable neuroprosthetic systems for the severely disabled. From 2002 to 2005, he was a Postdoctoral Fellow at the Department of Neurobiology and the Center for Neuroengineering, Duke University, Durham, NC, USA.

Dr. Carmena is a member of the Society for Neuroscience and the Neural Control of Movement Society. He is the recipient of the Bakar Fellowship (2012), the IEEE Engineering in Medicine and Biology Society Early Career Achievement Award (2011), the Aspen Brain Forum Prize in Neurotechnology (2010), the National Science Foundation CAREER Award (2010), the Alfred P. Sloan Research Fellowship (2009), the Okawa Foundation Research Grant Award (2007), the UC Berkeley Hellman Faculty Award (2007), and the Christopher Reeve Paralysis Foundation Postdoctoral Fellowship (2003).