Neurotechnology: An Engineering Perspective

Emerging Brain-Machine-Brain Interfaces (BMBIs) are promising alternative to study the neural activity underlying cognitive functions and pathologies, detecting mind driven decisions, etc. A BMBI covers many engineering and medical science disciplines. It includes biomedical circuits and systems, biosensor interfaces and devices, biosignal and bioimage processing, and bioinformatics, bioelectronics for brain science, and implantable electronics, biomedical instrumentation and imaging technologies, functional electrical neuromuscular stimulation, Lab-on-chip for diagnostic, and drug delivery devices, neural data recording, sorting, detection, and compression, etc. Resulting devices and algorithms translate physiological activity into machine language, which can be used to restore or enhance, either partially or completely, the human perceptive or sensory-motor functions.

Their numerous applications and fervent reception in the medical community have turned BMBIs into one of the most dynamic and interesting research topics nowadays. The implementation of a complete BMBI requires integrated circuits and microsystems design challenges, which include neural sensing and stimulation interfaces, wireless transmission, energy harvesting, signal processing, low-power and low-voltage circuits, and material sciences and biocompatibility.

Neurotechnology, including most of these activities, is motivating research community to focus on the implementation of various wireless microsystems intended for efficient bioprocessing algorithms for both sensing and actuating. In addition to the above summarized challenges and topics, neurotechnology covers brain imaging intended for both understanding neuroscience and clinical purposes. These various topics make neurotechnology fundamentally unique, and its revolution is so profoundly important.

Benefiting from this emerging fields, a deep understanding of how the mind perceives, thinks and acts within our grasp. Such an understanding will have a revolutionary impact on worldwide interests in pure, applied and medical sciences, and even economic growth. Technically, as the human central neural system is, long away, one of the most complex systems including hundred million neurons and synapses in only a few millimeter brain slices, BMBIs include a large number of microfabricated devices for brain-machine data communication using well-known recording and electrical stimulation techniques.

Based on this emerging neurotechnology, the constitution of neural networks, their function, and their mechanisms resulting on specific behavior are investigated. For example, investigating the interneurons connections to produce a certain function such as learning or memory is one of challenging goal. The connection of neurons to produce complex cognition and behaviors are inspiring researchers to build neuromorphic and other bioinspired circuits, simulate massive neuron networks, and to construct devices of artificial neurons or using tissues of real neurons. Hebbian model of neural circuits, Hodgkin-Huxley model of an action potential, FitzHugh-Nagumo, and most importantly artificial neural networks are outcome of such studies that can be employed to model parts of artificial brain to solve very complex problems for instance related to economical growth.

In addition to biologically inspired science, the neurotechnology has an influence on the diagnostics and the treatment of neural diseases as mentioned above. Among these diseases Epilepsy, Alzheimer and Parkinson occupy important place in the treatment through deep brain stimulation. The technological advances are likely to have a great impact on the quality of life and participation in individuals with spinal-cord injury (SPI), as BMBI is expected to restore motor function and probe neural circuits lost as the results of SPIs. The same strategy is made for controlling robots with mind driven decision.

On the other hand, blindness disease due to eye pathology, retina damage, optical nerves dysfunctions or damage of the lateral geniculate nucleus as well as many other complications coming from the visual cortex remains one of the most complex brain functions. In fact, the development of medical devices for sight restoration in the blind is underway. Several human trials with neural prostheses are undertaken and early results across the teams are promising. With commercially available devices perhaps only a few years away, all eyes will be on this newest emerging neurotechnology, the application of bioelectronics to the human nervous system.

Using permanent microelectrodes, three approaches, are actually considered world wide to develop such visual stimulator: 1) The retinally based, which are two main types: The subretinal using electrode array between retina and pigment epithelium to stimulate retinal cells, and the epiretinal using electrode array on vitreal surface to stimulate ganglion or bipolar cells. 2) The optic nerve based, which uses cuff electrode around optic nerve or array of penetrating electrodes to stimulate optic nerve directly, and 3) The cortically based, that is divided into two categories: The extracortical in which the electrodes are implanted subdurally over surface of visual cortex, and the intracortical using electrodes implanted directly in the visual cortex. This latest technique, the intracortical stimulation, is under investigation by pioneering researchers in the neurostimulation arena.

Through advances in neuroscience, implantable microelectronics and the emergence of an industry around increasingly complex and powerful medical devices, the possibility of true BMBI technology is upon us. In addition to brain disease, the neurotechnology can efficiently be used to address dysfunctionalities in body members such as a urinary bladder stimulator, which can be used to promote bladder control (emptying and storage) in SPI patients.

Despite landmark research activities, only few devices are commercialized derived from neurotechnology. For instance, aspire the Vagus nerve stimulator has recently cleared in market for mostly be used for epilepsy through open loop manner. As the follow up this achievement, the development of a closed loop stimulator system using the seizure detection is an important challenge. Medtronic has also described the clinical use of its implantable deep brain stimulation systems for Parkinson's disease and essential tremor is supported.

In the next few years, system able to handle hundreds of microelectrodes having 3D shape as well as optogenetic methods will be on place helping to achieve expected major discoveries. Collaborating with multidisciplinary researchers in order to validate efficiency of developed complex systems is mandatory. In addition, testing in the upcoming years complex systems in human brain gives hope to provide solutions to central neural systems dysfunctions.

Basic and Clinical Neuroscience may bring together the research community in both medical and engineering areas under a single roof for a fruitful coordination, promoting a cross-fertilization of ideas and state-of-the-art research activities.

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