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Proceedings of the Eighth International Workshop on Advances in Electrocorticography

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ABSTRACT

Excerpted proceedings of the Eighth International Workshop on Advances in Electrocorticography (ECoG), which convened October 15–16, 2015 in Chicago, IL, are presented. The workshop series has become the foremost gathering to present current basic and clinical research in subdural brain signal recording and analysis.
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1. Introduction

A. Ritaccio

The Eighth International Workshop on Advances in Electrocorticography (ECoG) took place on October 15–16, 2015, in Chicago, IL. The workshop series, now in its seventh year, has had the annual opportunity to present its proceedings to the readership of *Epilepsy & Behavior* since its inception. As found by a recent Scopus search, nearly one-third of ECoG-related research publications in peer-reviewed journals over the past decade have been authored by past and present faculty of this meeting. The Eighth International Workshop contained 16 authoritative research presentations and reviews over a compact 2-day gathering. Advances in engineering and in the use of ECoG for the detection of disease states represented the most novel content, and we have decided to excerpt these in this summary document.

2. Engineering

2.1. Advanced materials for thin-film microECoG devices

Justin Williams

There has been a push over the last decade in the development of microECoG devices that are based on thin-film microfabrication processes. This has resulted in a number of studies that utilize various flexible polymers as the insulating substrate for microfabricated devices to record high-resolution activity from the surface of the brain [1]. Although much work has been put into making insulating substrates more flexible, little attention has been given to the electrode elements because of the intrinsic flexibility of most metallic conductors and their extremely thin cross-section due to metallic deposition techniques.

With the advent of new genetic engineering approaches, there also has been increased interest in devices that are compatible with optical imaging and stimulation techniques. It is now commonplace to use transgenic animal models that express genetically encoded proteins that allow for optical activation or optical imaging of neurons in the

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living brain [2]. As a result, numerous studies have been developed to integrate neural recording devices with optical delivery methods. These approaches all suffer from utilizing traditional insulators and conductors that are either optically opaque or made of semiconductors that produce optical artifacts. More recently, investigators have started to explore methods to incorporate optically clear conductors in an attempt to produce devices that do not interfere with optical imaging and modulation.

One of the recent approaches has been to incorporate single crystal graphene sheets as the conducting elements of implantable microECoG electrodes [3]. Graphene is not only optically transparent but also highly conductive as well as extremely flexible. It also has a uniform transparency across a wide range of the optical spectrum, making it applicable to a variety of imaging and optical stimulation techniques, from optogenetic modulation of channel rhodopsin with blue light to multiphoton imaging with infrared light [2]. Graphene is part of a class of newly developed materials classified as "2D" materials, which take on exceptional new properties as one of their dimensions approaches atomic levels [3]. These types of materials have recently been explored in other neural engineering applications for interfacing with single neurons in culture, because they can be formed into self-rolling tubes that mimic the size and the mechanical and electrical properties of the natural myelin sheath that normally insulates axons [4]. These examples foreshadow the potential for utilizing other 2D materials in future neural interface applications.

3. Basic science

3.1. The application of "brain–machine-interfacing" to neuromodulation: enabling an evolutionary and translational prosthetics roadmap?

Tim Denison

Modulating neural activity through stimulation is an effective treatment not only for epilepsy but also for several other neurological diseases such as Parkinson's disease and essential tremor. Opportunities for improving modulation of neural activity include reducing the burden of optimizing stimulation parameters, objectively measuring efficacy over time, and continuously adjusting therapy to optimize patient outcomes [5]. Achieving these goals is challenging given several practical issues, including the paucity of human data related to disease states, poorly validated patient state estimators, and evolving nonlinear mappings between estimated patient state and optimal stimulation parameters.

The application of brain–machine-interface (BMI) technology to existing stimulator architectures could help address these issues and potentially enable smarter future "prosthesis" systems for neural circuits impacted by disease. Referencing Fig. 1, we developed an investigational, implantable, bidirectional neural interface system based on commercially released device architectures [5]. The research system provides stimulation therapy while simultaneously recording and classifying physiological signals from neural circuits [6]. The modularity of the system provides investigational access to both cortical and subcortical circuits simultaneously, which can facilitate the dynamic characterization of brain networks, their relationship to disease, and how stimulation impacts these dynamics. To aid in the integration of the physiology and hardware, the architecture connects the implanted sensing and stimulation pathways with externalized algorithms, which are performed in a local computer and linked via telemetry [7]. The use of a distributed architecture allows for interactive prototyping of both classification algorithms for diagnostics and dynamic actuation controllers for exploring closed-loop operation. As the understanding of the neural system matures, the implant can be wirelessly upgraded for completely embedded operation, self-contained in the implant [8].

The bidirectional BMI research system is currently deployed with investigator-sponsored clinical studies worldwide. Two examples of research using the tool were discussed at this workshop (vide infra): Dr. Philip Starr discussed exploring movement disorder circuits with an emphasis on Parkinson's disease, and Dr. Aysegul Gunduz discussed exploring networks associated with Tourette disease. In each case, physiological markers correlated with clinical state are informing classification algorithms and dynamic actuation controllers. In general, the process involves two stages: first, characterizing the network transfer function and training the classifier by sensing the physiological response to stimulation or pharmaceuticals, and then second, applying these functions as the basis for a dynamic closed-loop algorithm [8].

From a practical point of view, and as demonstrated by the investigational work described at the workshop, neuromodulation therapies offer a unique and practical opportunity for *translating* ECoG BMI technologies into a clinical research setting [9]. Several neurological disease treatments apply invasive device stimulation therapies, and the addition of sensing and algorithm technology is an obvious *evolutionary* expansion of capabilities if the benefits of the capability clearly offset any incremental risks or costs. While initial investigational applications are focused on epilepsy and movement disorders, the technology is potentially transferable to a broader base of disorders, including stroke and rehabilitation.

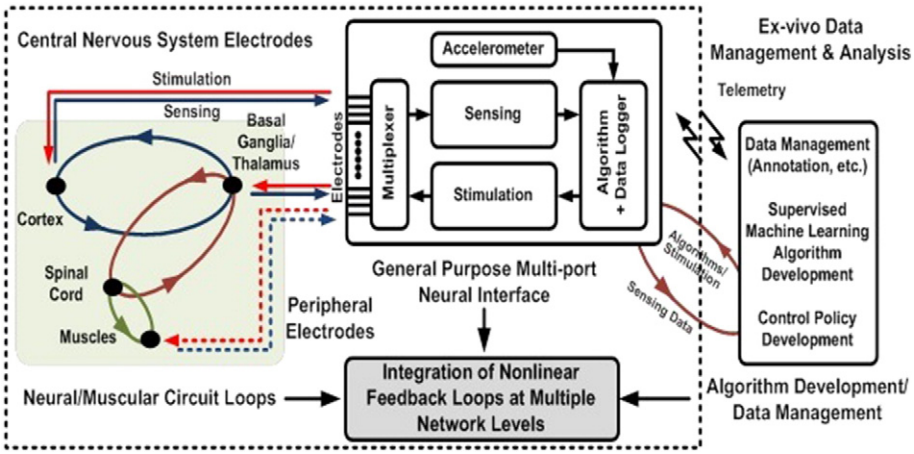

Fig. 1. Block diagram of the investigational research system being used to characterize cortical and subcortical neural networks in human disease. See work by Starr (Section 4.1) and Gunduz (Section 4.2) for representative examples of its use.

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