Recent Advances in Brain-Computer Interface Research—The BCI Award 2013

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1 Introduction

Brain-Computer Interfaces (BCIs) are devices that can enable communication or control without movement. The BCI detects specific patterns of the user's brain activity that reflect different messages or commands that the user wants to send, such as spelling or changing a television channel. Signal processing tools then decode this brain activity to identify the desired message or command, then send this message to an output device. BCIs are closed-loop systems, meaning that the BCI must provide the user with some information in real-time that (hopefully) reflects the intended message or command.

One defining feature of any BCI is the method used to record brain function. Many approaches have been explored, and new ones are often introduced—some later in this book. Most modern BCIs rely on one of the following four methods:

Electroencephalography (EEG) records the brain's electrical activity from electrodes that are usually embedded in an electrode cap. This cap usually requires 5 min to mount on the user and adjust electrodes to get a good signal, although

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newer systems that require less time have been developed. EEG systems are relatively inexpensive and portable, and are the most common neuroimaging method in BCI research.

Electrocorticography (ECoG) involves recording electrical activity from electrodes that are surgically implanted on the surface of the brain. Relative to EEG sensors, ECoG sensors have better spatial resolution, and can accurately detect brain activity at high frequencies that are invisible to EEG electrodes. Once implanted, the electrodes can be ready for BCI use or other tasks without preparation before each use.

Depth electrode recording uses electrodes that are surgically implanted in the brain. This approach has appealing features similar to ECoG, but records activity from a smaller group of neurons. Hence, these two approaches provide a different picture of brain activity.

Functional Magnetic Resonance Imaging (fMRI) does not measure electrical activity, but instead measures the brain's blood flow changes associated with different mental activities. These changes cannot be detected with the temporal precision as the three approaches above. fMRI systems require a very powerful magnetic field, and thus cost millions of dollars and are not portable.

The two middle procedures require neurosurgery to implant the electrodes. Of course, this procedure is only considered when medically necessary, such as prior to epilepsy surgery or for severely disabled patients with few or no other communication and control options. This neurosurgical procedure is expensive, and may not be viable for some patients. Hence, invasive BCIs are only practical for some users. On the other hand, new research in this book and elsewhere is showing that invasive BCIs may provide some communication or rehabilitation options that are otherwise unavailable.

After the signal has been recorded from the brain, signal processing mechanisms must determine which signal the user wanted to send. Signal processing often involves many steps to customize the BCI to a specific user and environment, such as finding the best electrode sites, removing unwanted information (such as electrical noise caused by muscle movement or external devices), determining the best frequencies, and choosing the optimal classifier and classifier parameters. After this, the signal travels to an output device. Early BCIs typically sent signals to monitors, and newer BCIs have been used to control devices including orthoses, wheelchairs, online applications, entertainment systems, or stroke rehabilitation systems. BCIs also differ in the types of mental activities that users perform for control, and the corresponding brain signals. Most BCIs rely on imagined movement or visual attention for control, but new directions are being explored and extended often. Ultimately, the best BCI for each user depends on the user's medical condition (if any), needs, goals, preferences, usage environment, and other factors.

Over the last several years, BCI research has expanded in many different ways. BCI publications are becoming increasingly common in journals and books. The first journal devoted only to BCIs, called the BCI Journal, was launched in late 2013. BCI conferences and workshops are becoming more common and drawing more attendees. Videos and media articles about BCIs are increasingly popular online.

New BCI systems are being tested with a broader range of patient groups, providing new options for communication and rehabilitation. This increase in BCI activity has fostered some exceptional projects that merit additional attention.

2 The BCI Award

To encourage top quality BCI research, g.tec established the annual BCI Awards in 2010. g.tec was formed in 1999 and produces equipment and software used in many BCI labs, as well as numerous research articles. To enter the competition, each team must submit a two-page research summary, detailed on the BCI Award website. The competition is open to any team, and submissions have come from a wide variety of regions and disciplines. The submissions may include different types of hardware and/or software, and must include results from real-world testing and validation.

Each year, a different top research institution is asked to recruit a Chairman of the Jury, who will develop a jury to judge these submissions. This jury consists of respected BCI researchers, which judges the submissions based on the **Award Criteria** below. The jury then chooses ten nominees, who are announced publicly and invited to a gala award ceremony attached to a major BCI conference. Finally, the winning submission is announced at this ceremony. The winning team receives a certificate, trophy, and 3,000 USD. The Award is also a major honor; even being nominated is a significant accolade in the BCI research community. Furthermore, the ten nominees are invited to contribute a chapter to this annual book series, which summarizes their projects along with related work, analyses, discussion, and new directions.

Each jury is asked to select the nominees and winner based on specific **Award Criteria**:

- Does the project include a novel application of the BCI?
- Is there any new methodological approach used compared to earlier projects?
- Is there any new benefit for potential users of a BCI?
- Is there any improvement in terms of speed of the system (e.g., bits/min)?
- Is there any improvement in system accuracy?
- Does the project include any results obtained from real patients or other potential users?
- Is the used approach working online/in real-time?
- Is there any improvement in terms of usability?
- Does the project include any novel hardware or software developments?

The BCI Award has rapidly developed into a top honor within the BCI community. In 2013, 169 projects were submitted, almost triple the number of submissions in 2012. The 2013 Award Ceremony attracted a record number of attendees, and hundreds of BCI researchers and developers awaited the announcement of the winner with great suspense. Our book chapters reviewing the 2011 BCI Award has been downloaded over 10,000 times. The 2014 Award should be more competitive than ever.

3 The 2013 Nominees

This year, the jury was chaired by Theresa Vaughan from the Wadsworth Research Laboratory, who selected Drs. Douglas Weber, Adam Hebb, Donatella Mattia, Andrzej Cichocki, Adam Wilson, and Surjo Soekadar as jury members. Continuing with prior tradition, the jury included the winner of the previous year's award, Dr. Soekadar. These jury members are all from esteemed research institutes around the world, with expertise including signal processing, neuroscience, medicine, invasive and non-invasive BCIs, and real-world BCI use with patients.

Choosing ten nominees out of 169 submissions was very hard, and many interesting submissions from well-known BCI groups had to be rejected. The following projects were nominated for the 2013 BCI Award:

"Give me a sign: The possibilities of using hand gestures as a control signal for implanted brain computer interfaces"

M.G. Bleichner[a], J.M. Jansma[a], Z.V. Freudenburg[a], E.J. Aarnoutse[a], M.J. Vansteensel[a], N.F. Ramsey[a]

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"An Ipsilateral, Contralesional BCI in Chronic Stroke Patients"

D.T. Bundy[a], E.C. Leuthardt[a]

[a]Washington University, St. Louis, MO, USA

"A learning-based approach to artificial sensory feedback: intracortical microstimulation replaces and augments vision"

M.C. Dadarlat[a,b], J.E. O'Doherty[a], P.N. Sabes[a,b]

[a]Department of Physiology, Center for Integrative Neuroscience, San Francisco, CA, USA

[b]UC Berkeley-UCSF Bioengineering Graduate Program, University of California, San Francisco, CA, USA

"Motor recovery of chronic writer's cramp by brain-computer interface rehabilitation: A pilot study"

Y. Hashimoto[a], T. Ota[b], M. Mukaino[b], J. Ushiba[c]

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[b]Department of Physical Medicine and Rehabilitation, Asahikawa Medical University Hospital, Asahikawa, Hokkaido, Japan

[c]Department of Biosciences and Informatics, Faculty of Science and Technology, Keio University, Yokohama, Kanagawa, Japan

"Cognitive signals for brain-machine interfaces: an alternative paradigm to neuroprosthetics control"

I. Iturrate[a], R. Chavarriaga[b], L. Montesano[a], J. Minguez[a], J. del R. Millán[b]

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[b]Defitech Foundation Chair in Non-Invasive Brain-Machine Interface, EPFL, Lausanne, Switzerland

"An Accurate, Versatile, and Robust Brain Switch for Neurorehabilitation"

N. Jiang[a], N. Mrachacz-Kersting[b], R. Xu[a], K. Dremstrup[b] and D. Farina[a]

[a]Department of Neurorehabilitation Engineering, Bernstein Center for Computational Neuroscience, University Medical Center, Göttingen, Denmark

[b]Center for Sensory-Motor Interaction, Department of Health Science and Technology, Aalborg University, Aalborg, Denmark

"Ear-EEG: Continuous Brain Monitoring"

D. Looney[a], P. Kidmose[b], M.J. Morrell[a,c], D.P. Mandic[a]

[a]Imperial College London, UK

[b]Aarhus University, Denmark

[c]Sleep Unit, Royal Brompton Hospital, London, UK

"A hybrid brain computer interface for adaptive workload estimation in rehabilitation robotics"

D. Novak[a], B. Beyeler[a], X. Omlin[a], R. Riener[a,b]

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[b]Spinal Cord Injury Center of Balgrist University Hospital, Switzerland

"A concurrent brain-machine interface for sequential motor function"

M. Shanechi[a,b], R. Hu[d,e], M. Powers[d], G. Wornell[c], E. Brown[d,e,f], Z. Williams[d,e]

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"Exploring an fMRI-guided minimally invasive subdural N200 speller"

D. Zhang[a], H. Song[a], R. Xu[a], B. Hong[a]

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These ten projects reflect substantial diversity in many ways. The projects include research to help people with visual deficits, hearing deficits, writer's cramp, stroke, and severe movement disabilities. This trend toward broader medical applications is consistent with the overall increase in medical applications for more types of patients. The projects entail a variety of methods for recording brain activity, including conventional methods like scalp recorded EEG and invasively recorded ECoG and unconventional approaches including ear-based EEG recording and activity modulated by direct sensory stimulation. The nominated teams come from a variety of backgrounds and academic disciplines, from China, The Netherlands, Japan, Denmark, Spain, the UK, Switzerland, and various institutes in the USA.

Because of the growing interest in the BCI Awards, and the quality of the nominated projects, we decided to create this annual book series so readers could learn about the top projects and trends in the BCI community. Each book includes an introduction and conclusion, written by the editors, that summarizes recent BCI trends, the selection procedure, nominees, and winner. The remaining book chapters are written by the nominees themselves, and present each of their projects in more detail than their original two-page submission. These chapters also include newer results, analyses, discussion, and future directions. This year, for the first time, we have added a chapter from a project that received an "Honorable Mention" from the jury, but was not nominated. This chapter includes noteworthy progress since the award submission, and its principal author has been selected as a member of the jury for the 2014 BCI Award.