Brain-Computer Interface Research: A State-of-the-Art Summary 5

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1 What Is a BCI?

Brain-computer interface (BCI) technology was first developed as a tool to provide basic communication, such as spelling, without movement. By detecting specific patterns of activity in the brain, BCIs can get a general idea of which messages or commands a user wants to send. For example, a user might pay attention to a flickering icon on a monitor with the letter "A" to spell that letter, or imagine left hand movement to move a cursor, wheelchair, or humanoid robot to the left. BCIs might detect brain activity through sensors outside the head, such as an electrode cap that detects the electroencephalogram (EEG) or sensors inside the head, such as electrocorticography (ECoG) activity that is detected during neurosurgery.

BCIs were initially developed to help patients with very severe motor disabilities, who otherwise could not communicate. The last several years have seen a shift to new patient groups and applications, such as helping stroke patients regain movement or helping neurosurgeons map the brain more accurately to perform surgery more quickly and safely. This book, and the awards from 2015, reflect and extend these trends, including BCIs to help new patient groups such as persons with cerebral palsy or severe brain damage.

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2 The Annual BCI Research Award

The Annual BCI Research Award is organized by G.TEC, a leading provider of BCI research equipment headquartered in Austria, with branches in Spain and the USA. Because of the growth of BCI research worldwide, G.TEC decided to create an Annual BCI Research Award to recognize new achievements. The international competition is open to any group doing BCI research, regardless of region, hardware or software used, prior publications, or other factors. The first Award was presented in 2010, and followed the same process that has been used in subsequent years:

- G.TEC selects a Chairperson of the Jury from a well-known BCI research institute.
- This Chairperson forms a jury of top BCI researchers who can judge the Award submissions.
- G.TEC publishes information about the BCI Award for that year, including submission instructions, scoring criteria, and a deadline.
- The jury reviews the submissions and scores each one across several criteria. The jury then determines ten nominees and one winner.
- The nominees are announced online, and invited to a Gala Award Ceremony that is attached to a major conference (such as an International BCI Meeting or Conference).
- At this Gala Award Ceremony, the ten nominees each receive a certificate, and the winner is announced. The winner earns $3000 USD and the prestigious trophy. In 2014, we added prizes for the 2nd place winner ($2000 USD) and 3rd place ($1000 USD).

Each year, the juries have scored the submissions based on several award criteria. Given the intensity of the competition, nominated projects typically score high on several of these 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. bit/min)?
- Is there any improvement in terms of accuracy of the system?
- 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?

Fig. 1 This picture shows attendees watching the Award Ceremony in the Cuvée in Chicago

The 2015 jury was:

- *Junichi Ushiba (chair of the jury 2015)*,
- *Msayuki Hirata*
- *Nuri Firat Ince*
- *Zachary Freudenburg*
- *José del R. Millán*
- *Sydney Cash*
- *Tomasz M. Rutkowski (winner 2014)*

Like previous BCI Awards, the jury included the winner from the preceding year (Dr. Rutkowski). The chair of the jury, Dr. Junichi Ushiba, is a top figure in BCI research and leads the well-known BCI lab at Keio University, Japan. Dr. Ushiba said: "I was very fortunate to work with the 2015 jury. All of the jury members that I approached chose to join the jury, and we had an outstanding team."

Also like previous BCI Awards, we held the annual Gala Award Ceremony in tandem with a major conference. In 2015, this was the annual Society for Neuroscience conference in Chicago, Illinois. The ceremony was held at the Cuvée in Chicago and was very well attended. Dr. Guger organized the event, with Dr. Allison acting as moderator. The ceremony began with an introduction of all projects that were nominated, and the recipients came onstage to receive their certificates. Next, we announced the first, second, and third place winners and presented their awards (Figs. 1 and 2).

Fig. 2 Christoph Guger (organizer), Christian Herff (nominee), Kenji Kato (nominee), and Brendan Allison (moderator)

3 The BCI Book Series

Each year, we ask the nominees to write a chapter for this book series. While these chapters mainly present the work that they submitted for the BCI Award, authors are also invited to present newer work, discussion, and related material. The authors who contributed to this book have all remained active since being nominated, and thus they all have newer work from as late as fall 2015.

One of our concerns in editing and managing the chapters is accessibility to non-experts. While chapters present advanced material, we have tried to explain many terms and develop figures and tables to help illustrate the BCI systems and the results. Students and newcomers to BCI research should be able to understand the different BCI advances presented in the chapters and why they matter. Also, like BCI research in general, the chapters here address a wide variety of disciplines, including neuroscience, psychology, engineering, mathematics, and medicine.

The chapters from this year's nominees are consistent with many broader trends in BCIs. Both invasive and noninvasive systems are presented, with a strong focus on online, real-world systems for patients. A few chapters aim to help patient groups that have been prominent in recent BCI research, such as diagnostic BCI tools for patients with disorders of consciousness (DOC) or BCIs to control prosthetic hands. Different chapters present original work that extends BCI technology to new patient groups, such as persons with chronic pain, cerebral palsy, or cerebellar damage. Two chapters show how invasive technology could be used to control finger movement or decode speech, which could lead to "literal" BCIs that

can directly decode imagined words. One chapter even presents BCI-based cockroach control. Overall, these chapters both reflect trends in BCI research and describe several novel directions.

4 Projects Nominated for the BCI Award 2015

In 2015, 60 high quality research projects were submitted from all over the world! The jury, chaired by Junichi Ushiba, carefully scored 10 nominated projects, and then selected the winner for the Annual BCI Research Award 2014. The ten nominees,[4] presented alphabetically by first author, were:

Peter Brunner, Karen Dijkstra, Will Coon, Jürgen Mellinger, Anthony L. Ritaccio, Gerwin Schalk (Albany Medical College and the National Center for Adaptive Neurotechnologies, Wadsworth Center, Albany, US).

An ECoG-Based BCI on Auditory Attention to Natural Speech

R. Chavarriaga[1], L.A. Gheorghe[1,2], H. Zhang[1], Z. Khaliliardali[1], J. d. R. Millán[1] ([1]Defitech Chair in Brain-Machine Interface, Center for Neuroprosthetics, EPFL, Lausanne, CH,[2] Mobility Services Laboratory, Nissan Research Center, Nissan Motor Co., JP).

Easy Riders: Brain-Computer Interfaces for Enhancing Driving Experience

Damien Coyle (School of Computing and Intelligent Systems, Ulster University, UK).

Sensorimotor Modulation Assessment and Brain-Computer Interface Training with Auditory Feedback in Disorders of Consciousness

Christian Herff[1], Dominic Heger[2], Adriana de Pesters[3], Dominic Telaar[2], Peter Brunner[3,4], Gerwin Schalk[3,4], Tanja Schultz[1] ([1]Cognitive Systems Lab, Universität Bremen, Bremen, DE, [2]Cognitive Systems Lab, Karlsruhe Institute of Technology, Karlsruhe, DE, [3]National Resource Center for Adaptive Neurotechnologies, Wadsworth Center, Albany, US, [4]Department of Neurology, Albany Medical College, Albany, US).

Brain-to-Text: Towards Continuous Speech as a Paradigm for BCI

Roni Hogri[1,3], Simeon A. Bamford[2,4], Aryeh H. Taub[1,5] ([1]Psychobiology Research Unit, Tel Aviv University, IL,[2] Complex Systems Modeling Group, Istituto Superiore di Sanità, IT, [3]Department of Neurophysiology, Medical University of Vienna, AT,[4] Inilabs Gmbh, CH,[5] Department of Neurobiology, Wiezmann Institute of Science, IL).

De Novo Experience-Based Learning in Rats Interfaced with a "Cerebellar Chip"

Guy Hotson[1], David P McMullen[2], Matthew S. Fifer[3], Matthew S. Johannes[4], Kapil D. Katyal[4], Matthew P. Para[4], Robert Armiger[4], William S. Anderson[2], Nitish V. Thakor[3], Brock A. Wester[4], Nathan E. Crone[5] ([1]Department of Electrical and Computer Engineering, Johns Hopkins University, US,[2] Department of Neurosurgery, Johns Hopkins University, US, [3]Department of Biomedical Engineering, Johns Hopkins University, US,[4] Applied Neuroscience, JHU Applied Physics Laboratory, US, [5]Department of Neurology, Johns Hopkins University, US).

Individual Finger Control of the Modular Prosthetic Limb Using High-Density Electrocorticography in a Human Subject

Kenji Kato, Masahiro Sawada, Tadashi Isa, Yukio Nishimura (National Institute for Physiological Sciences, Aichi, JP).

Restoration for the Volitional Motor Function via an Artificial Neural Connection

Guangye Li, Dingguo Zhang (Robotics Institute, School of Mechanical Engineering, Shanghai Jiao Tong University, CN).

Brain-Computer Interface Controlling Cyborg: A Functional Brain-to-Brain Interface between Human and Cockroach

N Mrachacz-Kersting[1], L Yao[2], S Gervasio[1], N Jiang[3], BD Ebbesen[1], TS Palsson[1], TG Nielsen[1], R. Xu[2], D. Falla[2], K Dremstrup[1], D Farina[2] ([1]Sensory-Motor Interaction, Aalborg University, DK,[2] University Medical Center, Göttigen, DE, [3]University of Waterloo, CA).

A Brain-Computer-Interface to Combat Musculoskeletal Pain

Sergey D. Stavisky, Jonathan C. Kao, Paul Nuyujukian, Stephen I. Ryu, Krishna V. Shenoy (Stanford University, US).

Increasing the Useful Lifespan of Intracortical BCIs by Decoding Local Field Potentials as an Alternative or Compliment to Spikes

5 Summary

The BCI Research Awards have continued to recognize and promote high quality BCI research worldwide. Our book series have been widely downloaded and have hopefully helped to teach and inspire a new generation of BCI researchers. The ten nominees from 2015 have kept the tradition of top-quality submissions alive, and the chapters that follow present many of the best BCI projects of 2015.