Brain-Computer Interface Research: A State-of-the-Art Summary 4

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What Is a BCI?

This book presents the latest research in brain-computer interface (BCI) systems. A BCI is a device that reads voluntary changes in brain activity, then translates these signals into a message or command in real-time. Early BCI work focused on providing communication for persons with severe movement disabilities. These patients have little or no ability to communicate in other ways, such as by speech, typing, or even most assistive technology (AT) systems meant for disabled users. For these patients, BCIs can provide the only means of communication.

All BCIs involve four components:

(1) Sensors measure brain activity.
(2) Automated software converts this activity into messages or commands.
(3) This information affects an output device in real-time.
(4) An operating environment controls the interaction between these components and the user.

Most BCIs rely on the electroencephalogram (EEG). These signals (also called "brainwaves") can be detected with electrodes on the surface of the head. Thus, these "noninvasive" sensors can detect brain activity with very little preparation.

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Some BCIs are "invasive", meaning that they require neurosurgery to implant sensors. These BCIs can provide a much more detailed picture of brain activity, which can facilitate prosthetic applications or surgery for epilepsy and tumor removal.

Automated software for BCIs requires several different stages. The raw data from the brain needs to be amplified and filtered. Spatial filtering can use signals from different electrodes to further reduce noise and improve signal quality. Additional preprocessing might further reduce noise, eliminate unnecessary data, or make data easier to process. Next, software must identify meaningful activity. This challenge depends on the BCI. For example, if the goal of the BCI is to detect hand movements to control a prosthetic device, then the software must determine which hand movement(s) the user is imagining.

This information is then sent to an output device. Common examples include a monitor, Smart Home system, prosthetic or other robotic device. The monitor might present feedback, such as whether the user is imagining left or right hand movement, which could move a cursor. Smart Home controls can control lights, doors, curtains, and other systems. Prosthetic limbs could restore control for many patients, and robotic devices such as a Functional Electrical Stimulator (FES) or robotic exoskeleton could be used for therapy.

Finally, an operating environment must provide seamless, real-time communication between the different software modules and the user. This can be especially challenging in some BCIs that have to work with EEGs, other input signals, and complex robotic devices. Some open-source software platforms are designed to help reduce the burden on academic and clinical researchers developing a BCI operating environment.

In the last several years, BCIs have improved in many ways. Dry electrodes can measure EEG with much less preparation time. New "passive" BCIs focus on monitoring changes in alertness, emotion, or other factors that do not distract the user. Different research groups have explored BCI technology to help communicate with persons who are (mis)diagnosed as comatose. Other work extends BCIs to help persons with stroke, memory or attention deficits, or other conditions. For example, BCIs that are integrated with a functional electrical stimulator (FES) or robotic exoskeleton can help people train to improve motor function that was lost due to stroke. Many of the chapters in this book present some of the top groups' newest work with BCIs to help new patient groups.

The Annual BCI-Research Award

G.TEC is a leading provider of BCI research equipment headquartered in Austria. Because of the growth of BCI research worldwide, G.TEC decided to create an Annual BCI-Research Award to recognize new achievements. The competition is open to any BCI group worldwide. There is no limitation or special consideration for the type of hardware and software used in the submission. 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.

The scoring criteria have also remained consistent across different years. These are the criteria that each jury uses to score the submissions. 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?

In 2014, G.TEC introduced second and third place winners. Because of increased interest in the Annual Awards, and increasing number of high-quality submissions, it seemed appropriate to honor second and third place as well. The jury selected these project based on their total scores. This change was well-received by the nominees and the BCI community, and will continue in later years.

Thus, this year's jury had an especially difficult task. Scoring was even more important, as small changes could influence second and third place. Indeed, the winners (presented in the concluding chapter) scored very close to other nominees this year. However, the jury spent a lot of time reviewing the 69 submissions, and the three winners were carefully chosen. The 2014 jury was:

Gernot R. Müller-Putz (chair of the jury 2014),
Deniz Erdogmus,
Peter Brunner,
Tomasz M. Rutkowski,
Mikhail A. Lebedev,
Philip N. Sabes (winner 2013)

Consistent with tradition, the jury included the winner from the preceding year (Prof. Sabes). The chair of the jury, Prof. Müller-Putz, is a top figure in BCI research and leads the prestigious BCI lab in Graz, Austria. Prof. Müller-Putz said: "I was very fortunate to work with the 2014 jury. All of the jury members that I approached chose to join the jury, and we had an outstanding team."

The Gala Award Ceremony has become a major annual event. These events attract several dozen BCI researchers each year, and major BCI conferences are scheduled around this evening dinner event to ensure that attendees can make it. The ceremony occurs at a formal location near the conference center, and includes beverages and several courses of gourmet dining. The annual announcement of the winner has always been suspenseful, and the addition of second and third place winners has made the ceremonies even more exciting.

In 2014, the Gala Award Ceremony was hosted at the prestigious Hotel Das Weitzer. This location had excellent dining and presentation facilities, and was close to the Sixth Annual BCI Conference in Graz, Austria in September 2014. The chair of the jury and the other two book editors introduced the Award, reviewed the ten nominated projects, presented certificates to the nominees, and then announced the winners.

Fig. 1 This picture shows the Gala Award Ceremony in Graz

Fig. 2 This image shows a group of six BCI researchers from different countries discussing their work at the Gala Award Ceremony. Facing the camera, from *left* to *right* David Ryan and Samantha Sprague (USA). On the other side of the table, from *left* to *right* Gernot Mueller-Putz, Chairman of the 2014 Jury (Austria), Andrea Kuebler (Germany), Donatella Mattia (Italy), and Nick Ramsey (Netherlands)

Fig. 3 One of the nominees, Dr. Jeff Ojemann (*left*), receives his nomination certificate

In addition to promoting BCI research through the Awards, the Gala Award Ceremonies have also provided a way for BCI experts to relax and interact. The attendees had just seen each other's posters, talks, and demonstrations. Many of them wanted to ask each other for more information, seek research collaborations, or just congratulate them on their good work. This can be difficult during the hectic conference schedule. Indeed, many of the discussions at the 2014 ceremony did lead to new research collaborations. Thus, the annual ceremonies have helped to encourage BCI research, along with the annual Award and book series. The following three pictures present the 2014 Gala Award Ceremony (Figs. 1, 2, 3).

The BCI Book Series

This annual book series is another important component of the Annual Award. Each year, G.TEC produces a book that reviews ten outstanding projects. Each group is responsible for writing a book chapter that presents their work. In addition to the work that was nominated, authors may also present related material, such as new work since their submission. Since the nominees are all from active groups, they often have new work that is worth reading. Each book in the annual book series also includes both introduction and summary chapters.

The book series is not just meant for experts in BCIs, engineering, neuroscience, medicine, or other fields. We editors have asked the authors to present material in a friendly manner, without assuming that the reader has a technical background. We also reviewed each chapter to improve readability. Chapters include figures and references to help support the text and guide readers to additional information. While chapters do introduce some advanced material, this book should be clear to most readers with an interest in BCI research.

This year's nominees, and their corresponding chapters, present a myriad of innovations in different facets of BCIs. The chapters include new invasive and noninvasive improvements, innovative signal processing, novel ways to control output devices, and new ways to interact with the user. For example, one chapter by Rutkowski and colleagues introduces an airborne ultrasonic tactile display, a new approach to touch-based interaction. Two chapters (by Ibáñez, Mrachacz-Kersting, and their colleagues) introduce new ways to use BCI technology to study brain plasticity and improve outcomes when patients conduct motor rehabilitation. Two other chapters (by McMullen, Boulay, and their colleagues) explore new BCIs to improve grasp function and other daily activities. These and other chapters present cutting-edge work that should lead to new directions in BCI research.

Projects Nominated for the BCI Award 2014

This year, the selection process was quite challenging. 69 top-level projects were submitted from around the world. The jury selected the following ten nominees in 2014, presented in alphabetical order:

- *P. Brunner[a], K. Dijkstra[a], W. Coon[a], J. Mellinger[a], A. L. Ritaccio[a], G. Schalk[a] ([a]Wadsworth Center and Albany Medical College, US)*
  Towards an auditory attention BCI
- *J. Gomez-Pilar[a], R. Corralejo[a], D. Álvarez[a], R. Hornero[a] ([a]Biomedical Engineering Group, E. T. S. I. Telecomunicación, University of Valladolid, ES)*
  Neurofeedback training by motor imagery based-BCI improves neurocognitive areas in elderly people
- *K. Hamada[a], H. Mori[b], H. Shinoda[a], T.M. Rutkowski[b,c] ([a]The University of Tokyo, JP, [b]Life Science Center of TARA, University of Tsukuba, JP, [c]RIKEN Brain Science Institute, JP)*
  Airborne ultrasonic tactile display BCI
- *J. Ibáñez[a], J. I. Serrano[a], M. D. del Castillo[a], E. Monge[b], F. Molina[b], F.M. Rivas[b], J.L. Pons[a] ([a]Bioengineering Group of the Spanish National Research Council (CSIC), [b]LAMBECOM group, Health Sciences Faculty, Universidad Rey Juan Carlos, Alcorcón, ES)*
  Heterogeneous BCI-triggered functional electrical stimulation intervention for the upper-limb rehabilitation of stroke patients
- *D. McMullen[a], G. Hotson[b], M. Fifer[c], K. Kaytal[d], B. Wester[d], M. Johannes[d], T. McGee[d], A. Harris[d], A. Ravitz[d], W. S. Anderson[a], N. Thakor[c], N. Crone[a] ([a]Johns Hopkins University School of Medicine Department of Neurology and Neurosurgery, [b]Johns Hopkins University Department of Electrical Engineering,[c]Johns Hopkins University Department of Biomedical Engineering,[d]Johns Hopkins University Applied Physics Laboratory, US)*
  Demonstration of a semi-autonomous hybrid brain-machine interface using human intracranial EEG, eye tracking, and computer vision to control a robotic upper limb prosthetic
- *K. J. Miller[a], G. Schalk[b], D. Hermes[c], J. G. Ojemann[d], R. P.N. Rao[e] ([a]Department of Neurosurgery, Stanford University, [b]Wadsworth Center and Albany Medical College, [c]Department of Psychology, Stanford University, [d]Department of Neurological Surgery, University of Washington, [e]Department of Computer Science and Engineering, University of Washington, US)*
  Unsupervised decoding the onset and type of visual stimuli using electrocorticographic (ECoG) signals in humans
- *N. Mrachacz-Kersting[a], N. Jiang[b], S. Aliakbaryhosseinabadi[a] R. Xu[b], L. Petrini[a], R. Lontis[a], M. Jochumsen[a], K. Dremstrup[a], D. Farina[b] ([a]Sensory-Motor Interaction, Department of Health Science and Technology, DK, [b]Dept. Neurorehabilitation Engineering Bernstein Center for Computational Neuroscience University Medical Center, DE)*
  The changing brain: bidirectional learning between algorithm and user

- *M. M. Shanechi[a,b], A. L. Orsborn[c], H. G. Moorman[c], S. Gowda[b], S. Dangi[b], J. M. Carmena[b,c] ([a]School of Electrical and Computer Engineering, Cornell University, [b]Department of Electrical Engineering and Computer Sciences, University of California, Berkeley, [c]UC Berkeley UCSF Joint Graduate Program in Bioengineering, US)*
  Rapid control and feedback rates in the sensorimotor pathway enhance neuroprosthetic control
- *F. R. Willett[a,b,c], H. A. Kalodimos[a,b,c], D. M. Taylor[a,b,c] ([a]Cleveland Clinic, Neurosciences, [b]Cleveland VA Medical Center, [c]Case Western Reserve University, Biomedical Engineering, US)*
  Retraining the brain to directly control muscle stimulators in an upper-limb neuroprosthesis
- *A. Wilson[a], R. Arya[a] ([a]Cincinnati Children's Hospital Medical Center, US)*
  Real-time bedside cortical language mapping during spontaneous conversation with children

Summary

Overall, the annual BCI Awards—along with the book series and ceremonies—have been successful in their main goal: to recognize top BCI research worldwide. They have also helped to bring BCI researchers together, encouraging discussion and collaboration among groups that might not otherwise communicate. These goals are addressed in a quote from Dr. Christoph Guger, CEO at G.TEC, presented on the annual Award websites:

> *"We have a vital interest in promoting excellence in the field of BCI. Achieving our goal to make BCIs more powerful, more intelligent and more applicable for patients' and caregivers' everyday lives strongly relies on a creative research community worldwide. The Annual BCI Research Award allows us to look back at highlights of BCI research in 20 years and to see how the field changed".*

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