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Christoph Guger · Brendan Z. Allison
Günter Edlinger *Editors*

Brain–Computer Interface Research

A State-of-the-Art Summary

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State of the Art in BCI Research: BCI Award 2011

Christoph Guger, Brendan Allison and Günter Edlinger

Introduction

Brain–Computer Interfaces (BCIs) analyze brain signals in real-time to control external devices, communicate with others, facilitate rehabilitation or restore functions (Wolpaw et al. 2002; Graimann et al. 2010; Wolpaw and Wolpaw 2012). BCIs, unlike other communication and control systems, rely on direct measures of brain activity. That is, people simply think, and a computer does the rest. In most BCIs, people must either think about performing certain movements, or pay attention to specific items on a monitor. However, many new BCI paradigms are emerging, many of which are discussed in this book.

The first BCI was described almost fifty years ago (Graimann et al. 2010). It was an invasive BCI, meaning that it relied on sensors placed under the skull via surgery. Almost ten years later, the first noninvasive BCI was published, in an article that also coined the term "brain–computer interface" (Vidal 1973). Like most BCIs today, it was based on the electroencephalogram (EEG) recorded from electrodes on the surface of the head (Allison et al. 2012). In other early work, Farwell and Donchin described a BCI that used the P300 brainwave for communication (Farwell and Donchin 1988). Up to the early 2000s, no more than 5 groups were active in brain–computer interface (BCI) research. Now, over 300 laboratories are focused on this work. This dramatic growth has been driven by many factors, including:

1. Cheaper, smaller, and faster electronics and related instrumentation;
2. Increased understanding of normal and abnormal brain function;

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3. Improved interfaces and environments;
4. Additional testing and experimentation with target users in field settings;
5. Improved methods for decoding brain signals in real time;
6. Improved sensors, such as active and dry electrodes and improved invasive electrodes.

The BCI Award

As a result, the performance and usability of BCI systems have advanced dramatically over the past several years. To highlight these trends and developments of BCI technology, g.tec began to sponsor an annual BCI Award in 2010. g.tec is a leading provider of BCI research equipment and has a strong interest in promoting excellence in BCI research (Guger et al. 2012). The prize, endowed with 3,000 USD, is an accolade to recognize outstanding and innovative research in the field of brain–computer interface research and application. The competition is open to any BCI group worldwide. There is no limitation or special consideration for the type of hardware or software used in the submission.

Each year, a renowned research laboratory is asked to assemble a jury, help judge the submitted projects and award the prize. This year, the jury was recruited by its chair, Dr. Gert Pfurtscheller of the University of Technology in Graz, Austria. The jury consisted of some of the most respected and accomplished experts in the BCI community: Theresa Vaughan, Michael Tangermann, Guan Cuntai, Robert Leeb and Jane Huggins. The jury selects and announces the winner and presents the prize.

The winner is announced at a public ceremony attached to a major conference. The 2010 BCI Award was presented at the BCI Meeting 2010 in Asilomar, California, and the 2011 BCI Award was presented at a gala dinner during the Fifth International BCI Conference in Graz, Austria (see Fig. 1). The 2012 Award was just presented at the Society for Neuroscience in New Orleans, Louisiana.

Fig. 1 The *left panel* shows the BCI Meeting 2010 in Asilomar, CA, where the 2010 BCI Award was presented. The *right panel* shows the gala dinner where the 2011 BCI Award was presented at the prestigious Hotel Gollner in Graz, Austria

The jury scored the submitted projects on the basis of the following 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 Ten Nominees in 2011

We received a total of 64 high quality submissions in 2011. Out of these submissions, the jury nominated the 10 nominees for the BCI Research Award in June 2011. Being nominated for the BCI Award is a major honor. Prof. Dr. Gert Pfurtscheller, Chairman of the 2011 Jury, said, "The BCI Award is outstanding because the whole world competes and only one project can win." Each nominee receives a certificate at the public ceremony, an invitation to summarize their work in a chapter in this book, and a mark of distinction on their resume or curriculum vita. Figure 2 presents two of the nominees receiving their certificates.

The authors, affiliations and project titles of the 10 nominated projects are:

Fig. 2 Both of these panels show nominees receiving the certificate for their team's project. The *left panel* shows (from *left* to *right*): Prof. Dr. Gernot Müller-Putz, organizer of the Fifth International BCI Conference; Prof. Dr. Gert Pfurtscheller, Chairman of the Jury; Lisa Friedrich, who is receiving the certificate for her nomination; Dr. Christoph Guger, CEO of g.tec, and Dr. Brendan Allison, the emcee. The same people are shown in the *right* panel, except that another nominee, Dr. Reinhold Scherer, is in the *middle*

- Tim Blakely, Kai Miller, Jeffrey Ojemann, Rajesh Rao (University of Washington, USA). Exploring the cortical dynamics of learning by leveraging BCI paradigms.
- Jonathan S. Brumberg, Philip R. Kennedy, Frank H. Guenther (Boston University, USA). An auditory output brain–computer interface for speech communication.
- Samuel Clanton, Robert Rasmussen, Zohny Zohny, Meel Velliste, S. Morgan Jeffries, Angus McMorland, Andrew Schwartz (Carnegie Mellon University, University of Pittsburgh, USA). Seven degree of freedom cortical control of a robotic arm.
- Felix Darvas (University of Washington, USA). Utilizing high gamma (HG) band power changes as control signal for non-invasive BCI.
- Elisabeth V. C. Friedrich, Reinhold Scherer, Christa Neuper (University of Graz, Austria). User-appropriate and robust control strategies to enhance brain computer interface performance and usability.
- Moritz Grosse-Wentrup, Bernhard Schölkopf (Max Planck Institute for Intelligent Systems, Germany). What are the neuro-physiological causes of performance variations in brain–computer interfacing?
- Eric C. Leuthardt, Charles Gaona, Mohit Sharma, Nicholas Szrama, Jarod Roland, Zac Freudenberg, Jamie Solis, Jonathan Breshears, Gerwin Schalk (Washington University in St. Louis, USA). Using the electrocorticographic speech network to control a brain–computer interface in humans.
- Daniele De Massari, Carolin Ruf, Adrian Furdea, Sebastian Halder, Tamara Matuz, Niels Birbaumer (University of Tübingen, IRCCS, International Max Planck Research School, Germany). Towards communication in the completely locked-in state: neuroelectric semantic conditioning BCI.
- Qibin Zhao, Akinari Onishi, Yu Zhang, Andrzej Cichocki (RIKEN, Japan). An affective BCI using multiple ERP components associated to facial emotion processing.
- Raphael Zimmermann, Laura Marchal-Crespo, Olivier Lambercy, Marie-Christine Fluet, Jean-Claude Metzger, Johannes Brand, Janis Edelmann, Kynan Eng, Robert Riener, Martin Wolf, Roger Gassert (ETH Zürich, Switzerland). What's your next move? Detecting movement intention for stroke rehabilitation.

Each of these ten projects is described in a separate chapter of this book.[1] Nominees described the projects they submitted, and provided some additional background material and new developments since their submissions. In the concluding chapter, the submissions are analyzed to show key properties and trends that help identify the dominant and emerging directions of BCI research.

[1] The 2010 nominees are summarized in **Recent Advances in Brain-Computer Interface Systems,** edited by Reza Fazel, InTech, 2011: State-of-the-Art in BCI research: BCI Award 2010.

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Conclusion and Future Directions

Overall, the BCI Awards have helped to encourage excellence in BCI research, identify key directions, and promote BCI research around the world. The ten projects summarized in this book represent some of the most promising accomplishments from the top research groups. However, the 2012 BCI Award, which is underway as of this writing, has so far been even more competitive than before. We editors plan a book summarizing the nominees, their follow-up work, and further analyses of major trends.

g.tec has already committed to host the fourth annual BCI Award in 2013. Researchers are encouraged to keep abreast of relevant announcements at bci-award.com, and consider submitting their research. Given the level of competition, extra time to develop the best submission is strongly recommended. We editors would like to conclude by thanking all the groups who submitted projects to the BCI Awards over the years, and the many other innovators in BCI research.