State of the Art in BCI Research: BCI Award 2010

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Introduction

The possibility of brain-computer communication based on the electroencephalogram (EEG) has been discussed almost four decades ago (Vidal, 1973). In another pioneering work, Farwell and Donchin described the use of evoked potentials for communication (Farwell, 1988). Up to the early 2000s, no more than 5 groups were active in brain-computer interface (BCI) research. Now, about 200-300 laboratories are focused on this work. This dramatic growth has been driven by high performance and low cost of computing power and related instrumentation, increased understanding on normal and abnormal brain functions, and improved methods for decoding brain signals in real time. As a result, the performance and usability of BCI systems have advanced dramatically over the past several years.

BCI systems can be described by the following characteristics: (i) invasive (electrocorticogram (ECoG), spikes) or non-invasive (EEG, NIRS (near infrared-spectroscopy), fMRI (functional magnetic resonance imaging), MEG (magnetoencephalogram)) systems (Leuthardt, 2004, Owen, 2008, Velliste, 2008, Wolpaw 2003, Pfurtscheller 2010a, 2010b), (ii) portable (EEG) or stationary (fMRI, ECoG, spikes), (iii) according to application area (spelling, wheelchair control, brain painting, research,…) (Sellers, 2010, Galán, 2008, Kübler, 2008), (iv) type of BCI principle used (P300, SSVEP (steady-state visual evoked potential)), SSEP (steady-state somatosensory evoked potential)), motor imagery, slow cortical potentials (Bin, 2009, Birbaumer, 2000, Pfurtscheller, 2010,Krusienski, 2006) (v) speed and accuracy, (vi) training time and reliability, (vii) synchronous and asynchronous, (viii) low cost (EEG, NIRS) and high costs (MEG, fMRI, spikes), (ix) degrees of freedom. A detailed review can be found in Allison (Allison, 2007). Over the last years the importance of specific properties changed, new technologies were developed that enabled new applications or made BCI systems affordable. For example, in the late 90s there were just a few real-time systems worldwide. At present, almost every lab is equipped with real-time BCI systems.

The BCI Award

To highlight these trends and developments of BCI technology, g.tec began to sponsor an annual BCI Award in 2010. 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. Each year, a renowned research laboratory is asked to judge the submitted projects and to award the prize. The jury consists of world-leading BCI experts recruited by the awarding laboratory. g.tec is a leading provider of BCI research equipment and has a strong interest in promoting excellence in the field of BCI to make BCIs more powerful, more intelligent and more applicable. 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. This year, the jury was recruited by its chair Dr. Gerwin Schalk of the Wadsworth Center in Albany, New York. It consisted of world-leading experts in the BCI community: Theresa Vaughan, Eric Sellers, Dean Krusienski, Klaus-Robert Mueller, Benjamin Blankertz, and Bo Hong.

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?

Table 1: Nominees of the BCI Award 2010.

Name and institution	**Title of BCI project**
Guangyu Bin, Xiaorong Gao, Shangkai Gao	A high-speed word spelling BCI system based on code modulated visual evoked potentials
Cuntai Guan, Kai Keng Ang, Kok Soon Phua, Chuanchu Wang, Zheng Yang Chin, Haihong Zhang, Rongsheng Lin, Karen Sui Geok Chua, Christopher Kuah, Beng Ti Ang	Motor imagery-based brain-computer interface robotic rehabilitation for stroke
Jing Guo, Shangkai Gao, Bo Hong	An active auditory BCI for intention expression in locked-in
Tao Liu, Shangkai Gao, Bo Hong	Brain-actuated Google search by using motion onset VEP
Harry George, Sebastian Halder, Adi Hösle, Jana Münßinger, Andrea Kübler	Brain Painting - "Paint your way out"
Mark Palatucci, Dean Pomerleau, Geoff Hinton, Tom Mitchell	Thought Recognition with Semantic Output Codes
David B. Ryan and Eric W. Sellers	Predictive Spelling with a P300-based BCI: Increasing Communication Rate
George Townsend	Innovations in P300-based BCI Stimulus Presentation Methods
Steven M. Chase, Andrew S. Whitford, Andrew B. Schwartz	Operant conditioning to identify independent, volitionally-controllable patterns of neural activity
Kimiko Kawashima, Keiichiro Shindo, Junichi Ushiba, Meigen Liu	Neurorehabilitation for chronic-phase stroke using a brain-machine interface

Out of 57 high quality submissions, the jury nominated the 10 top-ranked candidates for the BCI Research Award in April 2010. The jury then selected the winner of the 2010 BCI Award at the BCI 2010 conference in Monterey, California, in June 2010. The winning team was Cuntai Guan, Kai Keng Ang, Kok Soon Phua, Chuanchu Wang, Zheng Yang Chin, Haihong Zhang, Rongsheng Lin, Karen Sui Geok Chua, Christopher Kuah, Beng Ti Ang (A*STAR, Singapore) (Ang 2009), and their project was "Motor imagery-based Brain-Computer Interface robotic rehabilitation for stroke". This project represents a study with 26 subjects that combines current understanding of neurophysiology, rehabilitation, computer science, and signal processing to realize one of the most impressive studies in the rapidly growing area of brain-computer interfacing for stroke rehabilitation.

Table 2 shows a categorization of the BCI Award 2010 nominees into utilized control signals and application areas. The majority of 8 projects used EEG as input signal and 6 utilized the P300/N200 response. This has several reasons: (i) the EEG P300 response is easy to measure and a non-invasive method, (ii) it requires just a few minutes of training, (iii) works with the majority of subjects and (iv) gives a goal-oriented control signal that is especially suited for spelling and control application where no continuous control signal is needed (e.g., Internet surfing, painting). Actually, all the spelling/Internet/art applications were controlled with the N200/P300 strategy. Two projects used motor imagery (MI) in order to generate a continuous control signal. Both MI projects used the BCI system for the activation of the sensori-motor cortex for stroke rehabilitation that cannot be done with N200/P300- or SSVEP-based BCI systems. No SSVEP-based BCI systems were nominated for the BCI Award. This is surprising, because SSVEP-based systems achieve high accuracies and information transfer rate and can be operated by the majority of people. The reason could be that for goal-oriented control, the P300 principle is better suited because it gives more options by using standard computer screens. SSVEP-based systems require LED stimulators but can also use computer screens. Especially in the latter case, it is complicated to realize a high number of different frequencies. But it becomes more difficult for a high number of LEDs compared to arranging 50-100 icons on the screen for a P300 speller.

Table 2.Categorization of the BCI Award nominees.

Title	**Control signal**					**Application**		
	fMRI	**Spikes**	**N200/ P300**	**SSVEP**	**MI**	**Stroke**	**Spelling/ internet/art**	**Algorithm development**
A high speed word spelling BCI system based on code modulated visual evoked potentials			X				X	
Motor imagery-based Brain-Computer Interface robotic rehabilitation for stroke					X	X		
An active auditory BCI for intention expression in locked-in			X				X	
Brain-actuated Google search by using motion onset VEP			X				X	
Brain Painting - "Paint your way out"			X				X	
Thought Recognition with Semantic Output Codes	X						X	
Predictive Spelling with a P300-based BCI: Increasing Communication Rate			X				X	
Innovations in P300-based BCI Stimulus Presentation Methods			X				X	
Operant conditioning to identify independent, volitionally-controllable patterns of neural activity		X						X
Neurorehabilitation for Chronic-Phase Stroke using a Brain-Machine Interface					X	X		
Total	1	1	6		2	2	7	1

One fMRI- and one spike-based project were nominated. fMRI-based BCIs are more complicated to operate but have the big advantage of the good spatial resolution which allows to read out different control signals compared to EEG-based systems. Instead of selecting single characters, fMRIs can be used to extract, e.g., the semantic output code to form words and sentences, to play tennis, or to navigate in your home (Owen, 2008, Palatucci, 2009). Action potentials give the highest spatial and temporal resolution, but require implantation of electrodes within the cortex. Nevertheless, spikes allow a very accurate control of BCI systems and can even be used for robotic control with high accuracy (Velliste, 2008).

Table 3 lists different properties of all the 57 projects submitted to the BCI Award 2010. Of particular interest is the high percentage of real-time BCI implementations that exist nowadays. Motor imagery is still the mostly used strategy to control a BCI, followed by P300 and SSVEP. It is also not surprising that mostly EEG-based BCI systems are used because they are easier to handle and are cheaper. The mostly implemented application is spelling, ahead of general control (the papers did not mention a certain application) and stroke rehabilitation, wheelchair/robot or Internet control. 12.3 % of the submission introduced a BCI platform or certain improvements of technology.

Table 3: Properties of the submissions to the BCI Award 2010

Property	Percentage (N=57)	Property	Percentage (N=57)
Real-time BCI	65.2	Stroke	7.0
Off-line algorithms	17.5	Spelling	19.3
P300	29.8	Wheelchair/robot	7.0
SSVEP	8.9	Internet/VR	8.8
Motor imagery	40.4	Control	17.5
EEG	75.4	Platform/Technology	12.3
fMRI	3.5		
ECoG	3.5		
NIRS	1.8		

Conclusion

The BCI Award 2010 was the first international Award for BCI system development. The submissions highlight the current status of BCI technology. It is important to identify the most promising technologies and application areas for a faster grow of the community. g.tec plans to continue the BCI Award on an annual basis. This should provide annual snapshots of the progress of BCI research and its exciting new applications.

Acknowledgements

We are grateful to the members of the jury of the BCI Award 2010: Gerwin Schalk, Theresa Vaughan, Eric Sellers, Dean Krusienski, Klaus-Robert Müller, Benjamin Blankertz, Bo Hong. We also thank Aysegul Gunduz and Peter Brunner for their assistance with the evaluation process. Finally, we thank Theresa Vaughan and Jon Wolpaw for organizing the BCI conference 2010 as platform for the BCI Award 2010. The work was funded by the EC projects Decoder, Brainable, Better.

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