Brain-Computer Interface (BCI) based Musical Composition

Brahim Hamadicharef
Tiara #22-02
1 Kim Seng Walk
Singapore 239403
bhamadicharef@hotmail.com

Mufeng Xu, Sheel Aditya
School of Electrical & Electronic Engineering
Nanyang Technological University
Singapore 639798
{XUMU0001;esaditya}@ntu.edu.sg

***Abstract*—In this paper we present, for the first time in Brain-Computer Interface (BCI) research, a novel application for music composition. We developed, based on the I^{2}R NeuroComm BCI platform, a novel Graphical User Interface (GUI) to allow composition of short melodies by selecting individual musical notes. The user can select any individual musical key (quarter note with Do, Ré, Mi, Fa, Sol, La, Si, Do, etc.), insert a silence (quarter rest), delete (Del) the last note to correct the composition, or listen (Play) to the final melody, shown in text form and as a musical partition. Our BCI system for music composition has been successfully demonstrated and shown to be, with very short training time, effective and easy to use.**

This work is the first step towards a more intelligent BCI system that will extend current BCI-based Virtual Reality (VR) navigation for e.g. exploring a Virtual Synthesizer Museum/shop, in which the user would first move around within the virtual museum/shop and at the point of interest would try the synthesizer by composing music. More advanced modes (e.g. musical puzzle) with various levels of difficulty will be added in future developments as well as using the OpenVibe environment and mobile platforms such as the Apple's iPAD.

***Keywords*-Brain-Computer Interface; Musical Composition; Entertainment; Rehabilitation**

I. Introduction

Over the last few decades, Brain-Computer Interface (BCI) has gained undoubtedly popularity. From its first invention, traced back to 1973 with the research work of J. Vidal [1], and early years with pioneer research by J. Wolpaw [2][3], BCI has become a very active research field with a consequent literature as shown in a recent bibliometric study [4].

BCI are communication systems which enable users to send commands to computers (or any apparatus) by using brain activity only, this activity being generally measured by ElectroEncephaloGraphy (EEG) [5]. Today BCI systems find their applications in communication with word spellers [6][7] and control of wheelchair [8] and prosthesis [9]. We also witnessed new applications with robotic-arm rehabilitation for stroke patients [10], navigation in Virtual Reality (VR) [11], gaming [12] and even space [13].

BCI systems have yet to show their true potential for musical applications. Miranda and colleagues demonstrated some BCI systems [14][15] for controlling music, with however limited scope, influencing high-level of music such as rhythm and mood, thus making its effectiveness rather subjective to assess. Nevertheless, recent neuroscience studies are now probing some interesting links between the human brain and music. One study [16] investigated, for example, brain activities of adults and children processing music using functional Magnetic Resonance Imaging (fMRI) [17], another showing how music training leads to the development of timbre-specific gamma band activity [18]. A study in [19] detailed the recovery of a pianist from stroke.

Such findings motivated us to investigate the potential of BCI in music for composition encompassing the topics of gaming [20], entertainment and possibly rehabilitation (for e.g., in the treatment of autism [21][22]). We believe that there was a need to link BCI systems with music 1) to investigate other communication channel than spelling words, 2) to explore new BCI applications which could also provide novel ways of entertainment, and finally, 3) to stimulate brain-storming on future BCI research avenues while reviewing the limitations of the current state-of-the-art. Inspired from previous P300-based speller research [23], we thus proposed to investigate BCI for musical composition, i.e. allowing the user to compose (insert or delete a note in a musical partition and play) a short and simple melody using only his/her brain waves. More complex musical structures, such as chords, which would require a more sophisticated interface, are left for future work.

The remainder of this paper is organized as follows. In Section II we give a brief introduction to Brain Computer Interface, present the I^{2}R NeuroComm BCI platform with hardware and software components, and development of the new Graphical User Interface (GUI) for the musical composition. In Section III we discuss the achievements of this project and suggest future work.

II. Brain-Computer Interface (BCI)

A. Overview of the NeuroComm BCI platform

Our BCI is based on the BCI NeuroComm platform developed at the Institute for Infocomm Research (I^{2}R), Singapore. More details about this BCI NeuroComm and some of its applications can be found in [24]. Figure 1

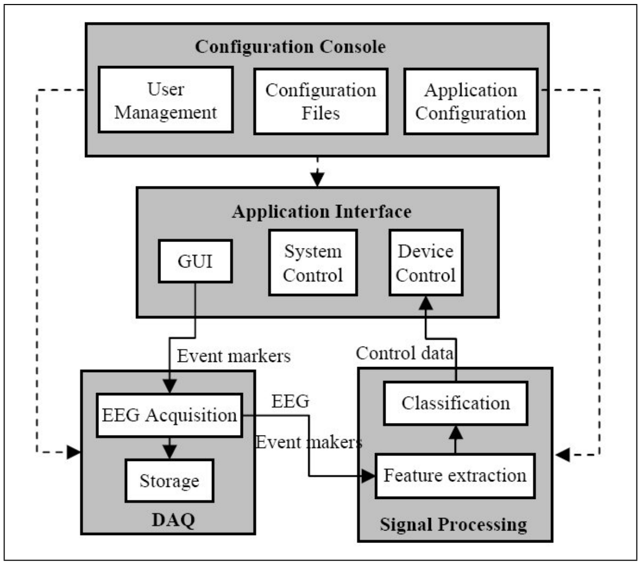
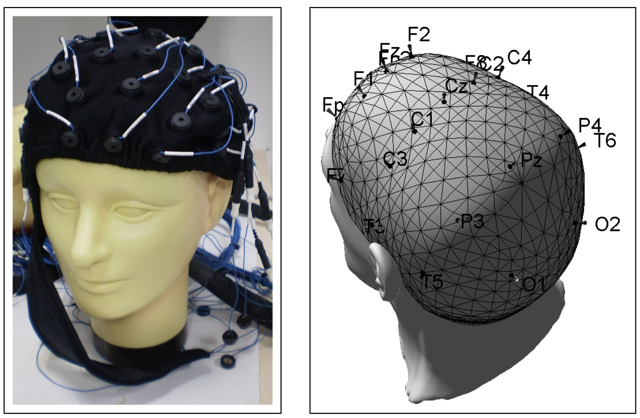


Figure 1. Overview of a typical BCI system [24]



(a) (b)

Figure 2. EEG recording with a) head cap and b) 10-20 system electrode locations

shows a conceptual diagram of the BCI system's internals. It consists of various software modules linked to the hardware and more specifically the configuration console, for the application interface (i.e. Graphical User Interface), the data acquisition module and signal processing (with classification). Briefly, the GUI provides the front-end for the use to interact, while the data acquisition module deals with the EEG hardware data flow, with finally the signal processing module processing the EEG data (short segments called trials), extracting important features such as the P300 waveform [25], and after correct classification, updating the GUI to provide feedback to the user. The GUI flashed randomly the GUI buttons which trigger the P300 waveform of the user, following the standard oddball paradigm [23].

B. Hardware

The hardware components consist of a NuAmps Digital EEG Amplifier from NeuroSCan Labs connected to an EEG head cap, as shown in Figure 2(a), fitted with electrodes following the standard 10-20 system location [26] (See Figure 2(b)). From the 32 available channels we use 15 channels with F3, Fz, F4, FC3, FCz, FC4, C3, Cz, C4, P3, Pz, P4, CP3, CPz, CP4. The NeuroComm BCI platform communicates with the hardware via the Application Programming Interface (API), buffering in real-time the EEG data. BCI setup can be seen from the demonstration video[1], with more technical details in [24].

C. P300-based BCI System

Part of general BCI NeuroComm platform is included a P300-based speller system based on the Asynchronous BCI research reported in [23]. The P300 [25] wave is an Event Related Potential (ERP) ring approximately 300ms after an elicited by infrequent, task-relevant stimuli, in our case randomly visual flashing of the GUI buttons (See lower part of the GUI in Figure 3). This is usually achieved using the oddball paradigm in which low-probability targets are mixed with high-probability ones. As the user concentrates his/her attention onto a specific button, the occurring ERP will appear in the EEG traces and subsequently extracted and classified to control the application interface.

D. GUI Software development

The software development has been carried out using the Microsoft Visual Studio (VS). The work has been focused on the main GUI form and associated GUI component to display the melody in form of text at the top and of real musical partition. Buttons for inserting specific notes were created plus one for deleting the last note (Del) and one for playing the final melody (Play). The final GUI is shown in Figure 3 and the demonstration screen-shots shown in Figure 4(c) and Figure 4(d). When the Play is selected, the application plays the melody with the Windows Sound system. The rest of the BCI application is based on the original I^{2}R asynchronous P300-based speller research [23]. The main contribution of this project is on the musical composition and design of the novel GUI for this specific purpose. More information can be found in FYP Report [27]

E. Novice/Expert Modes

Although the normal mode is simple enough to allow the user to compose melodies, we believe that more advanced modes for expert users can be incorporated in future developments. These include a *missing note* and *musical puzzle* modes. In the *missing mode* the user is shown a small melody with one or two notes missing from the partition display. The system will play the tune and including the

[1]Videos at http://www.tech.plymouth.ac.uk/spmc/brahim/BCI-Music/

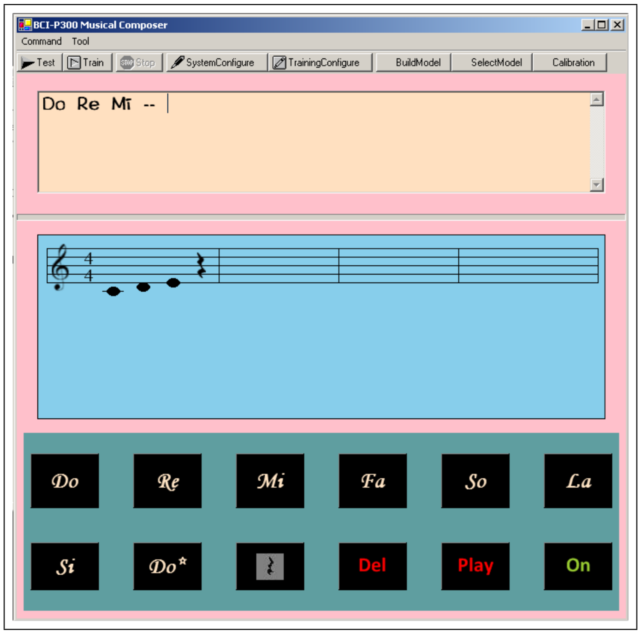


Figure 3. Final GUI for BCI-based musical composition

missing notes. The user will have to recognize the missing note and use the BCI system to select and insert them. If the right note is input by the user the system display a congratulation message and replay the tune to the user. If the user does not manage to find the right missing note, the system will try to propose the user with a less complicated tune. The complexity here is adjusted/modulated by the pitch difference of the the notes for e.g. A musical puzzle with an even more elaborate GUI could be designed in which a set of predefined notes are randomly presented to the user. The task will then be to re-organize the notes into the right melody (with presented cues). We believe that the current BCI system is the first step toward BCI systems with mode Artificial Intelligence (AI) that will help a great deal with the issues of usage and learning.

III. Discussion

As shown in a recent bibliometric study [4], there is growing interest in both research and development for BCI. However, current applications demonstrated are mainly centered on communication with word spelling, control with wheelchair, rehabilitation with neuroprostheses.

In this work we proposed, for the first time, to investigate BCI systems for musical composition. We argued that, like spelling words, creating short melody can provide an enjoyable experience for BCI users. A novel BCI system was developed and evaluated. This feasibility study and preliminary results are encouraging, with users assuring that the system robust (i.e. methodically evaluated [28]), easy and fun to use.

GUI will be further developed to include half (𝅗𝅥) and eighth (♪) notes, and even accommodate more complex musical structures such as chords such as found in professional music composition software (e.g. *Finale Music Composing & Notation* software).

This work is the first step toward the developments of BCI-based control of musical devices, such as Electronic Musical Instruments (EMI). To date only limited BCI research related to music has been published, with some attempt to influence music (rhythm or mood) and some investigations on EEG sonification [29], we believe that BCI can be used to control and adjust a synthesizer's sound parameters.

We believe that future BCI systems are likely to integrate more *intelligence* compared to the current and rather simplistic and limited paradigm. We could, for e.g., incorporate monitoring of the user's concentration [30][31] to adapt the level of difficulty (as in novice/expert modes) and include other multi-modalities with haptic feedback [32]. Novel research avenues would investigate brain activities for when the user imagine to press piano key piano action (motor imagery) and also imagine the piano sound (music imagery). Additional haptic feedback would also provide natural sensory mechanism related to sound vibrations.

The current project, based on the NeuroComm BCI platform, allowed to demonstrate the feasibility of BCI system for musical composition. In the future we are likely to use the OpenVibe [33], a free open-source BCI platform for research and development. Its demonstrations with Virtual Reality (VR) [11] systems make us believe that we could extend this project into a *Virtual Synthesizer Museum*, in which one would use BCI to move within a virtual museum and, at the point of interest, allow the user to compose music with a selected synthesizer and possibly control few sound's parameters.

Finally the mobile platforms, such as Google's Android-based devices and Apple's iPAD, can be considered as future portable platforms for BCI systems, in particular in the light of free Software Development Kit (SDK) and hardware resources such as GPU/CUDA [34].

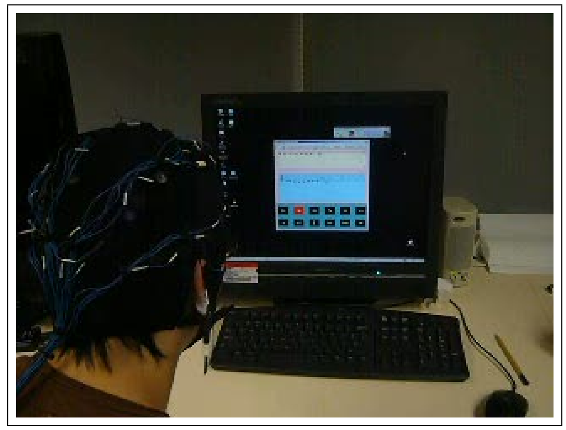
Acknowledgments

This work, based on the Final Year Project (FYP) of Mr Mufeng Xu for his graduate degree at the Nanyang Technical University (NTU), was carried out at the Brain-Computer Interface (BCI) Laboratory at the Institute for Infocomm Research (I^2R), Agency for Science, Technology and Research (A*STAR), Singapore. The authors thank Mr Chuanchu Wang for his support on the software development.

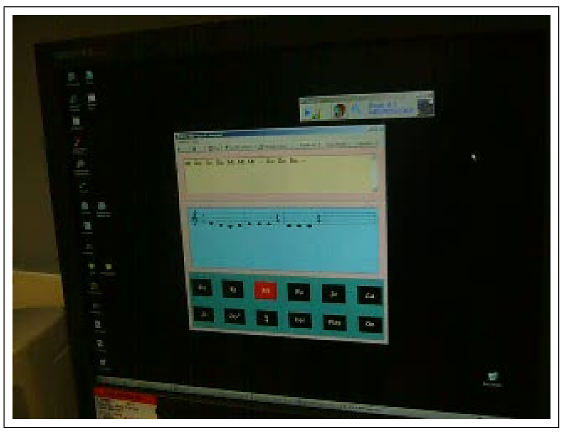
References

[1] J. J. Vidal, "Toward Direct Brain–Computer Communication," *Annual Review of Biophysics and Bioengineering*, vol. 2, pp. 157–180, June 1973.

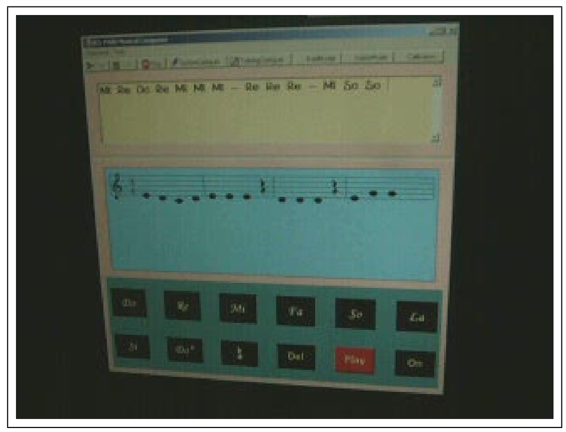
(a) Introduction



(b)



(c)



(d) Selecting play

Figure 4. screen-shots of the demonstration

[2] J. R. Wolpaw, D. J. McFarland, and G. W. Neat, "Development of an Electroencephalogram–based Brain–Computer Interface," *Annals of Neurology*, vol. 28, no. 2, pp. 250–251, August 1990.

[3] J. R. Wolpaw, D. McFarland, G. Neat, and C. Forneris, "An EEG–based brain–computer interface for cursor control," *Electroencephalography and clinical Neurophysiology*, vol. 78, no. 3, pp. 252–259, March 1991.

[4] B. Hamadicharef, "Brain–Computer Interface (BCI) Literature – A Bibliometric Study," *Proceedings of the 10th International Conference on Information Science, Signal Processing and their applications (ISSPA2010), Kuala Lumpur, Malaysia, May 10–13, 2010*, pp. 626–629.

[5] G. Pfurtscheller and C. Neuper, "Motor imagery and direct brain–computer communication," *Proceedings of the IEEE*, vol. 89, no. 7, pp. 1123–1134, July 2001.

[6] D. Krusienski, E. Sellers, F. Cabestaing, S. Bayoudh, D. McFarland, T. Vaughan, and J. Wolpaw, "A comparison of classification techniques for the P300 Speller," *Journal of Neural Engineering*, vol. 3, no. 34, pp. 299–305, 2006.

[7] B. Blankertz, M. Krauledat, G. Dornhege, J. Williamson, R. Murray–Smith, and K.-R. Müller, "A note on brain actuated spelling with the Berlin Brain–Computer Interface," *In C. Stephanidis, editor, Universal Access in HCI, Part II (HCII 2007), volume 4555 of LNCS, Berlin Heidelberg, 2007. Springer*, pp. 759–768.

[8] B. Rebsamen, E. Burdet, C. Guan, H. Zhang, C. L. Teo, Q. Zeng, C. Laugier, and A. J. M. H, "Controlling a Wheelchair Indoors Using Thought," *IEEE Intelligent Systems*, vol. 22, no. 2, pp. 18–24, March/April 2007.

[9] E. Donchin, K. M. Spencer, and R. Wijesinghe, "The mental prosthesis: Assessing the speed of a P300–based brain-computer interface," *IEEE Transactions on Rehabilitation Engineering*, vol. 8, no. 2, pp. 174–179, June 2000.

[10] K. P. Tee, C. Guan, K. K. Ang, and H. Zhang, "Augmenting Cognitive Processes in Robot–Assisted Motor Rehabilitation," *Proceedings of the 2nd Biennial IEEE/RAS–EMBS International Conference on Biomedical Robotics and Biomechatronics (BioRob), Scottsdale, USA, October 19–22, 2008*, pp. 698–703.

[11] F. Lotte, A. Van Langhenhove, F. Lamarche, T. Ernest, Y. Renard, B. Arnaldi, and A. Lécuyer, "Exploring Large

Virtual Environments by Thoughts using a Brain-Computer Interface based on Motor Imagery and High-Level Commands," *Presence: Teleoperators and Virtual Environments*, vol. 19, no. 1, 2010, (In press).

[12] A. Finke, A. Lenhardt, and H. Ritter, "The MindGame: A P300-based braincomputer interface game," *Neural Networks*, July 2009, in Press (Available online).

[13] C. Menon, C. de Negueruela, J. del R. Millán, O. Tonet, F. Carpi, M. Broschart, P. Ferrez, A. Buttfield, F. Tecchio, F. Sepulveda, L. Citi, C. Laschi, M. Tombini, P. Dario, P. M. Rossini, and D. De Rossi, "Prospects of Brain–Machine Interfaces for Space System Control," *Acta Astronautica*, vol. 64, no. 4, pp. 448–456, February 2009.

[14] E. Miranda, S. Roberts, and M. Stokes, "On Generating EEG for controlling Musical Systems," *Biomedizinische Technik*, vol. 49, no. 1, pp. 75–76, 2004.

[15] E. Miranda and A. Brouse, "Toward Direct Brain–Computer Musical Interfaces," *Proceedings of the 2005 International Conference on New Interfaces for Musical Expression (NIME05), Vancouver, BC, Canada, 2005*, poster.

[16] S. Koelsch, T. Fritz, K. Schulze, D. Alsop, and G. Schlaug, "Adults and children processing music: An fMRI study," *NeuroImage*, vol. 25, no. 4, pp. 1068–1076, May 2005.

[17] K. Friston, P. Jezzard, and R. Turner, "Analysis of functional MRI time–series," *Human Brain Mapping*, vol. 1, no. 2, pp. 153–171, 1994.

[18] A. J. Shahin, L. E. Roberts, W. Chau, L. J. Trainor, and L. M. Miller, "Music training leads to the development of timbre–specific gamma band activity," *NeuroImage*, vol. 41, no. 1, pp. 113–122, May 2008.

[19] J. F. Toole, D. L. Flowers, J. H. Burdette, and J. R. Absher, "A pianist's recovery from stroke," *Archives of Neurology*, vol. 64, no. 8, pp. 1184–1188, August 2007.

[20] A. Nijholt, "BCI for Games: A 'State of the Art' Survey," *Proceedings of the 7th International Conference on Entertainment Computing (ICEC2009), PAris, France, September 3–5, 2009*, pp. 225–228.

[21] R. Accordino, R. Comer, and W. B. Heller, "Searching for music's potential: A critical examination of research on music therapy with individuals with autism," *Research in Autism Spectrum Disorders*, vol. 1, no. 1, pp. 101–115, January–March 2007.

[22] L.-O. Lundqvist, G. Andersson, and J. Viding, "Effects of vibroacoustic music on challenging behaviors in individuals with autism and developmental disabilities," *Research in Autism Spectrum Disorders*, vol. 3, no. 2, pp. 390–400, April–June 2009.

[23] H. Zhang, C. Guan, and C. Wang, "Asynchronous P300–based Brain-computer Interfaces: A Computational Approach with Statistical Models," *IEEE Transactions on Biomedical Engineering*, vol. 55, no. 6, pp. 1754–1763, June 2008.

[24] C. Wang, H. Zhang, K.-S. Phua, T. H. Dat, and C. Guan, "Introduction to NeuroComm: a platform for developing real–time EEG-based brain computer interface applications," *Proceedings of the 29th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBS2007), Lyon, France, August 23-26, 2007*, pp. 4703–4706.

[25] T. W. Picton, "The P300 wave of the human event–related potential," *Journal of Clinical Neurophysiology*, vol. 9, no. 4, pp. 456–479, October 1992.

[26] H. H. Jasper, "The TenTwenty Electrode System of the International Federation of Societies for Electroencephalography and Clinical Neurophysiology," *Electroencephalography and Clinical Neurophysiology*, vol. 10, pp. 371–375, 1958.

[27] M. A. Xu, "BCI based Musical Composition," Final Year Project Report for the degree of Bachelor of Enginering (BEng) in Electrical and Electronic Engineering (EEE), School of Electrical & Electronic Engineering, Nanyang Technological University, Singapore, May 2010.

[28] B. Hamadicharef, "AUC Confidence Bounds for Performance Evaluation of Brain–Computer Interface," *Accepted to the 3rd International Conference on BioMedical Engineering and Informatics (BMEI2010), Yantai, China, October 16–18, 2010.*

[29] T. Hermann, P. Meinicke, H. Bekel, H. Ritter, H. Muller, and S. Weiss, "Sonifications for EEG Data Analysis," *Proceedings of the 2002 International Conference on Auditory Display Kyoto, Japan, July 25*, July 2002.

[30] H. Zhang, C. Guan, B. Hamadicharef, C. Wang, and K. Phua, "A Method and System for Concentration Detection," WO 2009/134205/A1, Singapore.

[31] S. C. Kleih, F. Nijboer, S. Halder, and A. Kübler, "Motivation modulates the P300 amplitude during brain–computer interface use," *Clinical Neurophysiology*, February 2010, (Article in Press).

[32] F. Cincotti, L. Kauhanen, F. Aloise, T. Palomäki, N. Caporusso, P. Jylänki, D. Mattia, F. Babiloni, G. V. amd Marnix Nuttin, M. G. Marciani, and J. del R. Millán, "Vibrotactile Feedback for Brain–Computer Interface Operation," *Computational Intelligence and Neuroscience*, p. 12, 2007, (ID-48937).

[33] Y. Renard, F. Lotte, G. Gibert, M. Congedo, E. Maby, V. Delannoy, O. Bertrand, and A. Lécuyer, "OpenViBE: An Open-Source Software Platform to Design, Test and Use Brain-Computer Interfaces in Real and Virtual Environments," *Presence: Teleoperators and Virtual Environments*, vol. 19, no. 1, 2010, (In press).

[34] J. A. Wilson and J. C. Williams, "Massively Parallel Signal Processing using the Graphics Processing Unit for Real-Time Brain-Computer Interface Feature Extraction," *Front Neuroengineering*, vol. 2, no. 11, July 2009.