PROGRESS REPORT ON THE EAVI BCI TOOLKIT FOR MUSIC: MUSICAL APPLICATIONS OF ALGORITHMS FOR USE WITH CONSUMER BRAIN COMPUTER INTERFACES.

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ABSTRACT

The Embodied Audiovisual Interaction Group (EAVI) present work in the development of a toolkit for Music Brain Computer Interfacing (BCI) that is generally applicable to a range of devices capable of acquiring brain signals through Electroencephalography (EEG), including research-grade and commercial consumer equipment. This toolkit features applications of BCI techniques commonly associated with traditional neurofeedback approaches, but also incorporates software capable of detecting Event Related Potentials (ERPs) for the purposes of making high-level musical decisions. We describe various approaches in the application of BCI to music in research-led, applied musical scenarios, including high-profile performances, presentations and public engagement contexts. This work is funded by the Arts and Humanities Research Council and The Arts Council of England, and is officially supported by commercial BCI manufacturer, Neurosky.

1. INTRODUCTION

In this paper work is presented relating to the current state of the Goldsmiths EAVI group's Music Brain Computer Interfacing (BCI) project. This project has received funding through a number of streams relating to research, development and practice, including the Arts and Humanities Research Council, the Arts Council of England, and BCI manufacturers. The toolkit utilises a range of techniques based on existing BCI approaches, whilst also applying more recent research in new BCI techniques, including ERP detection, described previously [1]. The toolkit has been tested both in the lab, recording studio and on tour as part of Finn Peters' 'Music of the Mind' album. In addition, the work is being developed by commercial partners as part of the three-year Arts and Humanities Research Council knowledge transfer "Sound, Image and Brain" project, itself building on research developed as part of the three year AHRC project "Cognitive and Structural Approaches to Contemporary Computer Aided Audiovisual Composition", which completed in 2010. The tools described are at various stages of development, with some being only in the preliminary stages of research.

2. RELATED WORK

Non-invasive BCI approaches are becoming common in both academic and commercial contexts as a result of low-cost dry electrode headsets such as the Emotiv Epoch [2] and the Neurosky Mindset [3]. These devices employ real-time signal processing techniques alongside dry electrode based hardware and are being aimed at the general public. However, they are also being adopted by interdisciplinary researchers due to their simplicity and efficacy. At present, none of these devices have specifically musical applications for use by the general public, but they are significantly cheaper than similar devices such as the IBVA [4], and entirely unlike the cost of research-quality EEG devices such as the g.Tec product range [5], significantly reducing the cost of EEG based applications.

Despite the challenges of working on such devices, the EAVI group is running long term funded projects exploring both the commercial and research potential of Music BCI using these and other devices. Most commonly, previous work in these areas utilised biofeedback as the primary method of operation, and these low-cost devices contain algorithms as standard for such applications. Music BCI has traditionally focussed on identical approaches - the analysis of spontaneous potentials and sensory motor signals [6]. David Rosenboom [7] details a number of early experiments that deal with bio and neurofeedback approaches. Furthermore, spontaneous potentials form the basis of Alvin Lucier's 1965 piece, *Music for Solo Performer*. An excellent survey of the use of EEG in musical performance and composition can be found in Miranda & Brouse [8]. Miranda et al have significant experience in applied neurofeedback for music. Many have commented on the difficulty of using neurofeedback effectively, and problems interpreting meaning from the EEG signal, despite analysis of spontaneous potentials being very robust.

Our toolkit builds on these approaches, improving them by applying new techniques on newer hardware, but most importantly our system includes the capacity for control via P300 Event related potentials (ERPs), as described previously at ICMC [1]. Significantly, our ERP spotting algorithms have been recently tested on the aforementioned consumer brain computer interfaces, and have been shown to work with 100% accuracy in some simple scenarios, and 78.5% in tests that identically replicate clinical P300 oddball paradigms.

3. PLATFORMS

Our initial work was conducted through the use of a g.tec g.Mobilab EEG device. This led to significant results that demonstrated the potential for the application of ERP EEG algorithms for some musical applications (although it is accepted that speed is still is an issue). Following this work, we have attempted to apply these same techniques to commercial hardware, specifically the Neurosky Mindset, with success. Most importantly, many of the techniques could potentially be used with any EEG device.

4. NEUROSKY MINDSET

The NeuroSky Mindset is a bluetooth EEG headset providing a single dry electrode which is placed against the forehead in order to obtain a general reading of the brain's electrical activity. It is also a bluetooth audio device with a mic and headphones. Whilst it was originally intended as a gaming device, it has recently been applied to a variety of other contexts ranging from interactive fairy tales to wheelchair control [9]. The device produces 10 channels of data: the noise reduced time domain signal from the electrode, power readings for 7 spectral bands extracted from the time domain signal and the subject's attention and meditation levels. The attention and meditation levels are interpretations of the spectral bands, where meditation loosely maps to alpha levels and attention's derivation is not specified in the device's documentation. However, Rebolledo-Mendez et al. reported a positive correlation between user-judged attention levels and those from the MindSet device [10]. An SDK is available which makes it quite trivial to access the data generated by the device. It is possible to access the data using C, Java or via a network port.

5. APPLICATIONS OF THE EAVI BCI TOOLKIT

The applications reported in this section have used a variety of methods to pass the data from the device to audio software. These methods have been collected together into the EAVI BCI Toolkit for Music. Currently available are a Processing based application which converts the data into OpenSoundControl messages, a Max external and an openFrameworks wrapper.

BCIs have been used to control and generate music in a variety of ways. Some of these methods were developed as part of composer, saxophonist and flautist, Finn Peters' `Music of the Mind' project.

5.1. Musical behaviour in response to a human conductor .

In 2008, Grierson applied the ERP technique using the g.Tec mobilab hardware to perform *Braindrop*, an audiovisual composition (real-time video projection and spatialised audio) comprising different sections produced by algorithmic processes. During the performance of the piece the algorithmic performance system offered choices to the performer using a standard ERP flashing approach. This allowed the performer to choose when and how algorithms should change, controlling the overall formal structure of the music. With up to 3 choices, the decision time was approximately 2-3 seconds. This approach demonstrates the use of ERP detection as a means to control the high-level elements of a piece of music or audiovisual composition, or even aspect of an adventure game. The piece was performed at the Goldsmiths Electronic Music Studio's Sound Practice Research Group Launch event alongside compositions by Dr Michael Young and Dr John Drever.

5.2. Brainemin

The `Brainemin' is a Theremin-like instrument which is controlled using the Neurosky BCI. The attention level from the MindSet is mapped to the pitch of the instrument. It moves between a fixed scale of pitches using portamento, where the higher the attention level, the higher the pitch. The meditation level is mapped to vibrato. Two Brainemins can be heard on the opening track of the `Music of the Mind' album, *Meditation*, controlled by 2 musicians. During live performances of this music, the 5 musicians in the band wear MindSets and control 5 Brainemins simultaneously. A Java program reads the data from the 5 headsets and sends the data over to SuperCollider, wherein the Brainemin itself is implemented.

5.3. Brain Controlled Arpeggiator

The Brain Controlled Arpeggiator is a synthesizer implemented in SuperCollider which is controlled by up to 5 people simultaneously, where their attention and meditation levels are used to provide a 10 dimensional control system. Parameters that can be controlled include note spread, note length, tempo and a range of synthesis parameters, which depend on the synthesis technique being used. During group performance the musicians each wear a MindSet and attempt to guide their parameters in their desired direction. It has been observed that some users very quickly gain tangible control of their meditation and attention levels. This system has been used in live performances and public demonstrations.

5.4. Markov pitch model

In 2009, Grierson demonstrated a real-time BCI Music technique at the Goldsmiths Knowledge Futures Conference. This was driven by features acquired through the Neurosky Mindset interacting with a Markov chain. A video of this demonstration can be seen here: (http://www.twitvid.com/7D5E6). This system has two voices, the first being a direct interpretation of signals acquired by the Mindset, quantised to a pitch system that centres around an area of pitch suggested by concentration levels. The second voice is a bass line which responds to alterations in pitched areas, changing the chord structure algorithmically. This interaction is intended to guide the player in the creation of areas of interest. As the player focuses on a specific area of pitch, variations are introduced. These variations can create greater or lesser interest, and the algorithm responds by developing or altering the music being played.

5.5. Event Related Potential Techniques

ERP techniques commonly involve the use of Electroencephalography (EEG) to monitor brain signals reliably occurring in response to specific stimuli, such as sounds and images. Due to their reliability, these techniques are widely used in psychology and medicine. In recent years they have become central to certain types of BCI research, particularly where a user has a range of options to choose from. ERP techniques can be used to present a series of options to the user, allowing them to make choices to complete a task, such as spelling a word.

The majority of ERP BCI applications attempt to illicit and detect a specific ERP signal called the P300 [11]. This is partly because it is easier to detect than many other ERP signals. It is also partly because the P300 occurs in response to novel stimuli, or stimuli that causes a break in a consistent pattern. As such, if a range of options are each presented to the user in a way that makes them appear novel, the user's current preference can be detected. In the main, when the paradigm is correctly implemented, it reliably reflects the conscious choice of the user from a field of many options successfully.

Our previous ERP work focuses on interactive audiovisual applications of P300 BCI techniques, predominantly interactive sound and music. Grierson's P300 BCI for music [1] was developed using the G.Tec mobilab wireless EEG device, and has been widely reported in the international press [1]. Current work focuses on detecting ERPs with consumer BCI devices. The quality of this technology is very poor when compared to the research-level equipment commonly used in such scenarios, and ERPs can be challenging to elicit and detect, as they are very difficult to differentiate from background noise in the EEG signal. Despite these problems, we have been able to make significant early progress in the application of ERP techniques using the Neurosky Mindset. Previously in the field of ERP on consumer technology, Campbell et all [12] have presented work demonstrating successful P300 ERP based BCI control of a contacts database on a mobile phone with a wireless headset. This work uses the Emotiv Epoch, a multi-electrode biosensing device. Our approach is similar, but functions instead on the cheaper and less obtrusive Neurosky. As far as we know, this is the first time P300 technology has been deployed on this device, and the first time it has been achieved on a single dry electrode EEG device.

At present we have only attempted to utilise existing, well understood, tried and tested ERP paradigms, known to elicit a P300 oddball response – a P3a. Stimuli are flashed randomly on the screen at regular intervals. We used blue circles and red squares as the stimuli, with the red square being the target. Each time a flash is triggered, a 400 millisecond chunk of EEG data is stored and tagged to the stimulus. At the end of each run, results for each stimulus are averaged together. Each stimulus has an averaged EEG signal associated with it. If the averaged signal contains an amplitude peak between 200 and 600 milliseconds after the onset of the stimulus, and the average area is greater than that of every other averaged peak area, it is judged to be a possible P300 target signal, as the target would be the peak with the highest average area under the peak. Although we are still working to collect more results, we can report what appears to be 100 % accuracy in correctly detecting the red square as the target when the square is significantly larger than the circle, and 78.5 % accuracy when the stimulus are the same size (across 7 subjects).

As this is still work in progress, we have not begun large scale field testing of these techniques. However, this is planned for 2011 as part of the 3 year AHRC funded “Sound, Image and Brain” Knowledge Transfer Project.

6. COMMERCIAL AND PUBLIC ENGAGEMENT

Finn Peters and Matthew Yee-King's Arts Council of England-funded 'Music of the Mind' project made exclusive use of the Neurosky Mindset for the purposes of musical performance, and led to high profile news coverage on the BBC 'Today' programme, and UK breakfast television. Neurosky specifically supported the project through the donation of 5 Mindsets for use in performance.

Aside from many live performances, Peters and Yee-King have also been involved in public engagement activities where the technology and performance techniques were explained to and used by the general public. These workshops have so far been conducted at various UK higher education institutes, the Manchester Science Festival and the London Science Museum. The feedback from the audiences has been very positive - the idea of brain controlled music is inspiring to many. This underlines both the reliability of the headset, and also the likelihood that more reliable interaction techniques could help the device generate significant public interest.

The project benefits from industrial partnership with a UK games company specialising in the use of BCI. Following a recent demonstration of the technique described herein, they have begun work on using our EAVI ERP BCI toolkit to develop commercial game prototypes that use related ERP approaches for reliable and stimulating gameplay.

In addition to Music of the Mind, the AHRC funded component of this project features solid collaborations with major UK institutions and public engagement bodies, including the Science Museum, London and soundandmusic.org. These organisations are now beginning a series of workshops funded as part of this project, featuring considerable public engagement including exhibition, installation, performance, interactive games and assistive technologies. Through collaboration with Lottolab and the Science Museum, we have already run a pilot public engagement event in preparation for future testing. During the pilot, over 200 participants took part in psychophysics and interaction experiments in just under

2 hours. As the Mindset appears relatively reliable and easy to use, we anticipate we can collect significant data from a very high number of participants at similar events.

7. CONCLUSION

There are several challenges in using BCI technology for real-time interaction with computer music systems. The choice of mapping from BCI outputs to musical inputs is key. A number of control options are available; continuous data can be derived from the live EEG signal and ERP techniques can elicit discrete choices. The best mappings may be achieved when there is a perceptual match between the players actions and their effect on musical output.

A problem particular to the use of BCI devices for musical control is the possibility of feedback loops. These can occur where the emotive effect of music in turn affects the players EEG response, disrupting control.

The Neurosky Mindset's headphones are inconvenient to use in live performance: being bluetooth only they cannot be easily used as monitors but they must be worn to generate the EEG signal. Wearing them with one headphone 'off-ear' has been our solution. A positive side effect of this was an improved contact between electrode and scalp. Neurosky's newer controllers avoid these issues through the use of a headband. While the Mindset emits a lower quality signal than higher-grade devices such as the g-tec, its higher data rate and vastly quicker setup time give it greater potential as a musical controller. Furthermore, the portability and low cost of this and other consumer interfaces opens the door to collaborative BCI work, such as the 'Music of the Mind' project.

8. REFERENCES

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