New Approaches in Brain-Computer Music Interfacing

Mapping EEG for Real-Time Musical Control

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Abstract— **This paper presents on-going research into the creation of performance and compositional tools using a Brain-Computer Music Interface (BCMI). The research demonstrates the suitability of the SSVEP (Steady-State Visual Evoked Potentials) technique of generating brainwave information to cognitively control music. Furthermore, it considers the practical implications of using brainwaves in music, and their effect on mapping input data to a musical system. Our research so far indicates the suitability of a BCMI as a Digital Musical Instrument (DMI) for performance, and highlights the need for further practice-led research in this field.**

Keywords- brain, music, mapping, digital, interface,

I. INTRODUCTION

This paper reports on continuing research into the field of Brain-Computer Music Interfacing (BCMI) at the Interdisciplinary Centre of Computer Music Research (ICCMR), Plymouth, UK. The concept of reading brain information has existed since the early 20th century but the idea of outputting music is comparatively new. The German scientist Hans Berger is cited as the first person to have read electrical brain information in 1924, naming this process the *Electroencephalogram* (EEG) [1]. The journal *Brain*, followed with an article in 1934 on the idea of listening to electrical brain information [2], but it was not until Alvin Lucier's 1965 performance, *Music for a Solo Performer,* that the realisation of brain information to control sound was presented as a viable concept.

Brain information is most commonly read via EEG, using electrodes placed on the scalp to measure the intensity of brain waves at differing frequencies. EEG is a complex method of analysis used in medicine for evaluating conditions including seizures, sleep disorders and brain diseases such as Alzheimer's [3]. Current technology allows EEG to measure brain information in real-time, and has the ability to feedback this information to a user, who has voluntary control over the EEG; a process commonly known as *neurofeedback* [4]. Neurofeedback is generated and controlled via SSVP (Steady-State Visual Evoked Potentials) and mapped to a musical system. Previous research at Plymouth has developed techniques using a BCMI allowing a user to control musical parameters by harnessing simple cognitive control (using relaxed and concentrated states of mind) over brain wave activity [5, 6].

Using cognitive rather than physical controls opens up potential for the design of assistive music technology and Digital Musical Instruments (DMI's) for musicians with severely limited physical movement.. Initial implementations of our system were built up as a case study for providing musical control for users with motor neural disabilities, through trials at the Royal Hospital for Neuro-Disability, in London [7]. Aside from therapeutic uses of the BCMI, our research is focused primarily in exploring the creative potentials that allow for wider use.

The focus of this paper is on mapping strategies developed in the initial stages of the research. In particular it looks at the characteristics of the current BCMI interface and evaluates the potential for its usage as a DMI. In this, it identifies several areas of consideration for researchers considering the design of a BMCI. For an overview of ICCMR's BCMI research please refer to [8, 9].

II. SSVEP (STEADY STATE VISUALLY EVOKED POTENTIALS)

The system presented here uses a technique known as *Steady-State Visually Evoked Potentials* (SSVEP) to generate brain activity based on signals read via EEG from the visual cortex within the brain. SSVEP is based on the principle that the visual cortex, the section of the brain that processes vision, produces an increase in brain wave activity in relation to what the eye can see. Specifically, flashing strobes of light at rates between approximately 8 - 20Hz trigger increases in the amplitude of brain waves of the same frequencies. In simple terms, the EEG reading can be used to determine whether a user is looking at a light flashing at a rate of, say, 8Hz by monitoring an increase of the 8Hz brain wave measured in the visual cortex. Our BCMI is able to feedback in real-time the brain wave responses triggered by visual stimuli. A user views icons on a computer monitor which are programmed to accept the incoming streams of data from the EEG and increase in size, relative to the amplitude of the brain waves. When a user gazes at an icon, the EEG reading is fed back to the visual interface and the icon increases in size in relation to the strength of the users gaze.

SSVEP provides the user the means of controlling the amplitude of a brain wave by looking at, or looking away from the flashing icon, which produces an ON or OFF state. Our BCMI uses four icons flashing at different frequencies presented on a computer screen. A user selects one of four icons by looking at one, and the corresponding amplitude of the relative frequency increases. Aside from the EEG reflecting whether or not a user is looking at the stimuli, the amplitude of brain wave intensity can also be measured. The harder [1] the subject gazes at an icon, the greater the amplitude of the corresponding brain wave increases and these gazes (slow, short, fast or quick) can act as gestures read by the musical system. The four icons provide stimuli to generate measurements over four independent brain waves, and in turn send values to the inputs of a musical system.

III. THE BCMI AS A REAL-TIME MUSIC CONTROLLER

The practicalities of performing with a BCMI are largely unreported and the characteristics inherent in using EEG for SSVEP have a significant effect on the suitability for such an interface to compose and perform music in real-time. Although our system is made from a mixture of medical-grade hardware combined with bespoke software tools, the following issues can be reasonably assumed to be inherent in other means of brainwave measuring, and not necessarily directly related to specific equipment.

A. Precision

Compared to control systems in acoustic instruments the BCMI offers precise real-time control, but in a non-traditional manner. This is partly due to the difficulty in generating extremely precise amplitudes of brain waves with SSVEP. For example, if an input range of 1 – 20 is mapped to trigger 20 different notes of a piano sound respectively, it would be possible for a user to roughly select from an area of notes, but it would be extremely difficult to select an exact note when instructed. While practice can improve precision, using this proportional method of control can result in a feeling of un-playability for a user. A related precision issue is the latency of brain signals reacting to gesture. Due to the biological nature of this input, this latency cannot be estimated as per a digital system, but also needs to be taken into account in the mapping strategy.

B. Sensitivity

Any system that amplifies a minute signal by multiples of thousands will struggle from a low signal-to-noise ratio. Combined with using biological information as the data source it is not surprising that a BCMI is sensitive to different users in different ways. Physiological elements can include the mass of hair between the electrodes and the head, tiredness or stress and any movement of head or body causing the electrodes to be displaced in anyway. Fortunately computer algorithms can be implemented to account for differing levels of sensitivity and allow for calibration where different users elicit differing ranges of amplitudes.

C. Interference

Sensitivity can result in electrical interference, and interference in a BCMI is expressed as levels of amplitude in alpha waves not elicited by the visual stimuli, called false positive values. These values need to be minimised and identified for elimination before they reach the musical system in order to prevent unwanted musical commands being performed having a detrimental effect on the users' control. Biological artefacts such as brainwaves read by electrodes but not generated by the stimuli can create interfering signals, as can elements affecting the interface's sensitivity such as tiredness. Electrical artefacts also need to be addressed and contained where possible, and can come from poor grounding of the electrodes, interference from nearby electrical equipment and cables and even a users' build up of static charge.

These three areas are key in informing the design of the mapping strategy, in order to retain as much control as possible over the system and for a user to feel connected to the BCMI as an instrument.

IV. MAPPING BRAIN-WAVES TO A MUSICAL SYSTEM

Mapping information in DMI design involves connecting the input controls to the musical engine, such as the internal connection between pressing a key on an electronic keyboard and the resulting pitch [10]. Hunt, Wanderley and Kirk [11] define mapping definitions based on the number of connections between the input and output parameters; one-to-one, one-to-many and many-to-many (combinations of one-to-one and one-to-many). Although this framework is useful for evaluating systems it does not take into account the relationship of the input control to the mapping, or any co-dependencies or rules a mapping may rely on. Goudeseme [10] recognises the intricacy offered in

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[1] The definition of how 'hard' or 'intense' a subject's gaze is difficult to quantify as it varies somewhat across individuals. In summary it is a combination of the time spent looking at an icon, the concentration level of looking at an icon, and the awareness of looking at an icon.

mapping design, coining the term High Dimensional Interpolation (HDI) to define mapping a large number of parameters to a small number of inputs where controls can be interpolated and connected using various techniques.

Through the development of appropriate software tools it is virtually possible to map any input control to any element of a musical engine. The mappings explored in our BCMI vary widely, depending on the compositional choices, the intended sonic result and the limitations of the input controls. Instead of summarising these mappings solely in numerical terms, the nature of how control is governed in our BCMI can be presented in parallel with Dean & Wellman's [12] Proportional-Integral-Derivative (PID) model. This approach defines control as the 'effect' of the input signal onto the outputs value, regardless of the number of parameters connected. Proportional control dictates that output values are relative to input; the output is value X because the input is X. Integral control provides an output value based solely upon the history of the input. Finally, derivative control gives an output value relative to the rate of change of the input signal.

These three techniques are adopted in a number of ways in the BCMI, and through the inclusion of conditional rules and variations allow for an abundance of creative implementations. As an example, a cello sound can be excited using the derivative measurement of one input value's increment and decrement. Alongside this control a second input uses an integral control to control a modulation index relative to the cello processing; an example of interpolating two different controls to manipulate just one sound. Aside from the cognitive levels of control (knowingly gazing at a specific icon) the BCMI allows for an element of generative control, defined by a layer of rules that lies underneath an icon's primary mappings. This can be useful for aesthetics, and artistically to highlight the integration of the two methods of creating meaning in such a system; composition and mapping.

A. Threshold values

To deal with the issue of precision of direct, proportional mapping greater precision could be gained by passing the alpha wave amplitude through a series of thresholds that in turn trigger functions. For example an amplitude scale of 1 - 20 could be broken down into the following algorithm.

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if input==5 play note C2
if input==10 play note D2
if input==15 play note E2
if input==20 play note F2
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These simple rules indicate that by increasing the amplitude of the corresponding alpha wave (by increasing the gaze intensity), a user can 'play' up and down through a series of notes. This particular technique was initially used during the aforementioned patient trials (when playing along to backing music) but this linear strategy was found to be limiting in its application for advanced control due to the difficulty of producing gestural control that is precise enough to pass thresholds at an exact time as dictated by a user. However, for more crude control this technique can be used for gestures where less precise measurements are required.

B. Timing

A major element used our BCMI mapping is the measurement of time. By calculating the time a user takes to complete a simple cognitive task allowed for a deeper provision of precise controls. Unlike proportional control, which could be difficult to precisely trigger when desired, flexibility was achieved by measuring when the user changed cognitive processes. This provided controls with various features to be exploited.

A 'hold and release' method of control, provided through the interface, allowed for a change in control to occur at the point of release. The time between the hold command and the release command being received from the interface allowed for unique commands to be selected for mapping. A computer algorithm acts as a time calculator and selector for measuring input values. When an input value increases, a timer begins until the value decreases. Upon this decrease the value of time is compared against a series of rules. In this example, the differences of time correspond to sending different messages to the performance system to start playing different elements of a drone sound.

The musical action to undertake is, therefore, chosen by the time of the hold command, preceding the release command, which coincides with the relative timing of the piece. The main success of this technique over the sole use of thresholds is the ability of the release command to trigger an action in the performance system at an exact moment controlled by the performer. This technique also allows the type of release action to be predetermined and then selected by the timing of the trigger function before the release functions. To aid the need for time awareness during performance a secondary interface is used that displays a digital clock.

Further depth can be added to this hold and release technique by applying a threshold and a time-delay rule to create a strategy utilised in manipulating sustained drone sounds. By defining a threshold input value, say for example 5, when the input value increases above 5 a hold function is activated. If the input stays above 5 then the hold command stays on, and if the value decreases below 5 the release command is actioned. To add some flexibility to this simple hold and release function, a time lag of three seconds is added to the hold function. Therefore if the input decreases below 5 for less than three seconds and then increases to above 5, the hold function remains. If the input decreases to below 5 for longer than three seconds then the release function is activated. This technique creates a rule whereby an icon needs to be fixated on constantly to generate a command sent to the performance system, akin to the constant attention required to play a sustained note on an acoustic instrument. Deviation from this attention is allowed for a time span of up to three seconds, allowing for the performer to utilise other input gestures to manipulate the sound via different parameters or to control other aspects of the music. This level of depth requires a high level of mental concentration and awareness of time, external to and in relation to the music within a performance.

C. Ordering

Using numerical ordering to generate and control electronic music can create layers of mapping control in performance. Similar to the 1970s children's electronic game Simon [2], the use of creating rules based on the specific order of gestural commands allows for conscious ordering, and at times when ordering is derived from other primary gestures and, as a result, is undertaken unconsciously. This method of mapping allows for underlying (and at times unknowing) layers of control to be applied in contrast to more direct primary controls utilised by the same icon, or icons. This helps to create a palette for deeper and subtler manipulation of sounds without relying on automated or scripted processes during performance. It also adds a small element of the unexpected during a performance, notably for the performer as they can hear and ultimately 'feel' the effects of their actions in new ways with every performance. In action, the more practice that was undertaken gave slow rise to a primitive learning of these rules, based on a memory learnt almost subconsciously (rather than through primary thought) through finding aesthetically pleasing combinations or gestures.

This level of mapping is best suited to parameters that were intended to move between stochastic boundaries, thus not allowing the performance to feel 'out of control' or slipping away from the grasps of the user.

V. DISCUSSION

The results from these initial explorations clearly indicate that SSVEP is more than capable of providing a foundation for investigating mapping techniques in using brain waves as a control source for music. It is believed that through these strategies outlined above, and when elements of the composition lead the mapping design, that a high level of control can be achieved for composing and performing music. This is manifest in a series of performances by the first author that demonstrate these techniques. These techniques can be seen in a video of a performance of 'The Warren' [13] More research into harnessing more precise control has been identified; precise in both the amplitude and time domains. Although the issues of interference and sensitivity may improve with advances in technology, these currently need to be high in the mind when designing mapping due to their adverse effects on user control. The three mapping strategies presented here can form a sound basis for designing a musical system controlled by using SSVEP. Future research intends to develop these by exploring other methods of generating meaningful EEG information.

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