MoodMixer: EEG-based Collaborative Sonification

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ABSTRACT

MoodMixer is an interactive installation in which participants collaboratively navigate a two-dimensional music space by manipulating their cognitive state and conveying this state via wearable Electroencephalography (EEG) technology. The participants can choose to actively manipulate or passively convey their cognitive state depending on their desired approach and experience level. A four-channel electronic music mixture continuously conveys the participants' expressed cognitive states while a colored visualization of their locations on a two-dimensional projection of cognitive state attributes aids their navigation through the space. *MoodMixer* is a collaborative experience that incorporates aspects of both passive and active EEG sonification and performance art. We discuss the technical design of the installation and place its collaborative sonification aesthetic design within the context of existing EEG-based music and art.

Keywords

EEG, BCMI, collaboration, sonification, visualization

1. INTRODUCTION

Alvin Lucier's *Music for Solo Performer* was premiered in 1965 at Brandeis University. Widely considered the first live brainwave music performance, it represented a break from the electronic music performance tradition of the time, and remains unique for a number of reasons. First, the performer's alpha (8-12.5 Hz) brainwaves drive percussion instruments directly through coupled amplifiers, allowing him to generate real acoustic events (not synthesized ones) at roughly 10 Hz. The resulting "acoustic" sound material contrasts with the synthesized or spliced concrète styles of electronic music making of the time. Even today, Solo Performer remains somewhat distinct as an electronic performance in its physically manifest yet acousmatic materials.

A second, more subtle and important distinction that *Solo Performer* holds, at least in 35 years of hindsight, lies in the active and purposeful nature by which the performer modulates his attentional state to produce these sound events. Approaches that we would now describe as sonification were common in the tape music community of the time, but Lucier avoided these in favor of a more active approach. Lucier describes his response in a 1981 interview,

> "... most of my colleagues at Brandeis said, "Oh, that's a wonderful idea. You ought to tape record it, speed the sounds of the brain waves up, slow them down, reverberate them, filter them".... I had to eliminate those [techniques] in order to get at the poetry of the piece, which demanded that a solo performer sit in front of an audience and try to get in that alpha state and to make his or her brain waves come out.[6]"

Thirty-eight years later, Steve Mann, James Fung, Ariel Garten and Chris Aimone produced the *Regen/DECONcert* series in which 48 participants donned wearable EEG hardware to manipulate musical parameters of a jazz ensemble performance [8]. The performers were not given any explicit instructions as to how they should manipulate their cognitive state; rather, the collective alpha activity of the population was mapped onto musical parameters directly.

These two pieces sit on the extremes of a passive-active sonification axis; while *Solo Performer* represents an active approach in which the performer is consciously manipulating his or her brain state to reach a desired musical effect, *Regen* embodies a passive approach where participants' EEG is used for musical purposes irrespective of any direct, conscious control on their part.

The passive-active continuum in EEG sonification systems – often referred to as brain-computer music interfaces (BCMI) [9] – can be seen as a specific instance of a more general passive-active-reactive categorization scheme recently proposed within the brain computer interface (BCI) community [13]. A *passive* BCI is one in which the cognitive state of the individual is unobtrusively "monitored" without conscious control on the part of the individual. Feedback is not a necessary component. An *active* BCI is a closed-loop system which derives its outputs from brain activity which is directly and voluntarily controlled by the user, independently from external events, with the intention of controlling an application. Real-time feedback indicating the current output state of the system is generally an essential component. A *reactive* BCI is similar to an active BCI. Here the system measures the neural response to external stimulation. The user exerts control over the system by voluntarily directing his attention or otherwise indirectly controling how the brain processes the external stimuli. One example of a reactive BCI system as a music interface is Mick Grierson's adaptation of a standard "P300 Speller" BCI to allow an individual to compose musical note sequences by selectively attending to different symbols randomly illuminated on a computer display. When the attended symbol is briefly illuminated, the brain generates a neural response, which is detected in the EEG, and used to produce an associated note [3].

Solo Performer and *Regen* also exemplify two extremes of a solo-collaborative sonification axis. *Solo Performer*, like many contemporary BCMI systems, involves a single individual interacting with the system in isolation. EEG-based musical performances with multiple performers, while far less common than solo performances, date back to Rosenboom's 1971 *Ecology of The Skin* [12]. Here EEG alpha power from ten observer-participants was used to control ten parts of a synthesized sound texture. This is an early example of a collaborative BCMI in which the state of the system is determined by the neural state of two or more individuals. More recently, Miranda and Brouse proposed a "collaborative audification" approach in their Internet-enabled *InterHarmonium* project which introduces additional possibilities for large-scale collaborative BCMIs [9]. *Regen* embodied an extreme end of the collaborative sonification spectrum wherein the state of the music interface was determined by the collective neural activity of a large number of people.

Our *MoodMixer* project was conceived to incorporate aspects of both the active and passive approaches to EEG-based music creation while using hardware, data treatments, and electroacoustic and visualization techniques to facilitate a multiuser, collaborative approach.

2. COLLABORATIVE SONIFICATION

The performance instructions for the installation are as follows: The two participants sit in a room, each wearing a comfortable wireless EEG headset, as depicted in Figure 1. From each EEG data stream, two indices, each measuring a different aspect of the participant's cognitive state, are calculated. By mapping each measured state onto a one-dimensional axis, each participant is able to independently "navigate" within a shared two-dimensional musical interface; in this way, the musical aesthetic at a given point in time is determined by the combined cognitive state of both participants. In this instantiation, location along the ordinate (x-axis) is determined by a calculated index that roughly corresponds to the degree of relaxation or "meditation", while location along the abscissa (y-axis) is determined by an index corresponding to the participant's level of sustained attention or "focus." Another active control option is provided, as sound samples and visual flashes may be triggered by individual eye blinks or predefined blink sequences.

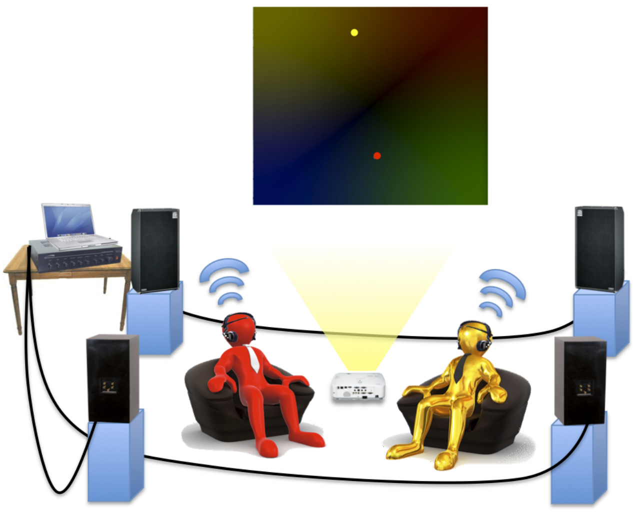

Figure 1: Depiction of the installation in use.

Novice participants may wish to adopt an observational relationship with the system as their changing cognitive state is passively monitored and represented in the audiovisual landscape. As participants use the feedback to gain experience in manipulating their neural state and actively controlling the interface they may shift to an "active" regime where they may choose to "improvise" and independently experiment with combinations of music drawn from two different regions of the music landscape. Alternately, participants may choose to attempt to cooperate closely with each other in creating a composition by mirroring the other's affective state (e.g., if one participant is in a relaxed, but focused state, the other should attempt to do likewise). Participants may define "games" which they play with each other. For instance, during a "calm" interval one participant might execute a sequence of blinks triggering a sound sample or visual pulse intended to induce dramatic changes in the arousal of the other participant, and thereby a dramatic shift in the evolving composition. Real-time visual feedback of each participant's current position (represented as a colored cursor) in the two-dimensional musical landscape affords an increased sense of control and interactive engagement in the compositional process.

2.1 Technical Design

The technical architecture of the system is depicted in Figure 2. In our first implementations we have used the Neurosky MindSet^{TM}, a relatively low-cost (< \$200) wearable EEG system[1]. As seen in Figure 2, the system features a "headset" design with a single active electrode (left or right prefrontal cortex), as well as reference and ground electrodes on the earlobes. The headsets utilize "dry" (gel-free) sensing technology and feature integrated Bluetooth, allowing data to be streamed wirelessly to a laptop. Raw EEG data from the single electrode is sampled at a rate of 512 Hz. Spectral power in the delta (0.1-3 Hz), theta (4-7), alpha (8-12 Hz), low, midrange, and high beta (12-15, 16-20, and 21-30 Hz, respectively) are calculated on the headset once per second using fast fourier transforms. Two cognitive state indices ("focus" and "meditation/relaxation") are then calculated using specific combinations of these bandpower features intended to correlate with the degree of focused attention/cognitive load and meditation/relaxation [1, 11]. Although the specific combination of features is proprietary to Neurosky, it is well-known that frontal alpha power is positively correlated with relaxation and/or meditative states of mind, while frontal beta power is positively correlated with increased concentration and focus. Experimenting with our own frequency ratios confirmed this. However, Neurosky's indices are based on a large normative dataset and thus provide immediately useable (if only approximate) normalized (0-100%) estimates of the indicated cognitive state without the need to collect any calibration data. The raw EEG data stream and relaxation and focus indices are streamed into a Max/MSP/Jitter patch via a Bluetooth connection using an external by Kyle Machulis[2]. The index values are then smoothed using a four-second moving average. The smoothed indices are used to control a four-way equal loudness panner which assigns the relative loudness "weights" of four audio tracks, each containing music material representing a combination of two of the cognitive index extremes (e.g., high focus, low relaxation). The music mix is projected via a four-channel surround sound system to create a spatial representation of the participant's mental state.

MoodMixer incorporates a two-dimensional colored visual

[1] http://www.neurosky.com
[2] http://www.nonpolynomial.com

representation (implemented in Jitter) in which each vertex of a square represents a combination of extreme values of the two cognitive indices. The square is comprised of a weighted mixture of four colored gradients, each associated with one vertex of the square, the weights of which are determined by the four-way panning curve. Each participant is given control of a uniquely-colored cursor, indicating his or her position in the two-dimensional cognitive landscape. Specifically, the participant's two cognitive indices are respectively mapped to the x- and y- coordinates of the cursor. Thus, as each cursor approaches a given vertex, the luminosity of the associated color gradient is smoothly increased (and that of other vertices proportionately decreased) in accordance with the levels of the associated cognitive indices. This approach is conceptually similar to Jacqueline Humbert's 1974 *Brainwave Etch-A-Sketch* in which two individuals, by manipulating their alpha power, each control the x or y position of a point of light on two-dimensional analog interactive display [12]. However, Humbert's approach is restricted to exactly two participants. Giving each participant independent control over both axes allows the interface to be used by one or many individuals, expanding the range of possible applications.

Participants have the option to use eye blinks to trigger sounds and visual effects. Eye blinks are detected by calculating, in real-time, the standard deviation of the raw EEG signal within a short (200 ms) sliding window. If the standard deviation exceeds a predetermined threshold, a blink is indicated and an event may be triggered. For example, a blink can trigger a pulsatile flash which emphasizes the quadrant(s) wherein the participants' cursors are located, optionally accompanied by a short audio sample (e.g., a drum beat). Another option allows the use of predefined sequences of eye blinks within a specified time interval to trigger a larger repertoire of events, including additional audio samples or visual effects. Although some care is taken to reduce false positives, for instance, suppressing an event trigger if the interval between two consecutive suprathreshold events is less than 40 ms, as often occurs in movement or muscle artifacts, more complex and accurate blink detection routines can be implemented and may be used in future versions of the installation.

2.2 Mixing Music to Match Mental States

The music mix was designed to fulfill a few simultaneous expectations: first, each of the four tracks represents a combination of extreme values along the two axes, which, when listened to in isolation, were intended to subjectively represent that particular extreme state. For instance, one might include samples of beat-driven, yet ambient music to reflect an alert/focused yet relaxed state of mind. Alternately, more spastic, unpredictable samples of music could be chosen to reflect states of high focus and low relaxation (anxious, agitated). However, due to the aleatoric nature of the design, there is a relatively low probability of the tracks being heard on their own for a sustained period of time. The tracks mesh together effectively so that any combination of all four tracks would sound good together while also conveying a state in between the focus-relaxation extremes. This was primarily achieved in an intuitive fashion, by composing with music samples representing a particular extreme, but having a sonic palette and rhythmic profile in common.

3. DISCUSSION AND FUTURE WORK

Future manifestations of this system will focus on expanding the collaborative aspect of the design and explore other

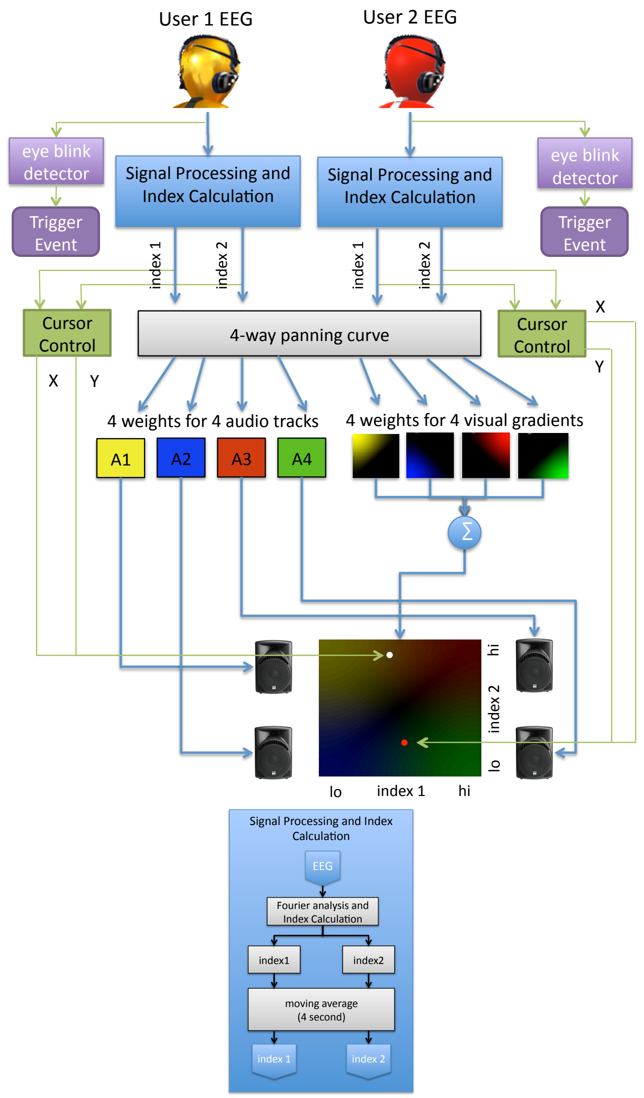

Figure 2: Diagram of the installation hardware setup with the communication protocols between components. In our installation, index1 corresponds to "relaxation/meditation" and index2 to "attention/focus"

treatments of EEG data to extract indices which can represent a wider range of cognitive and affective states. Due to its use of relatively inexpensive and easily obtainable hardware, *MoodMixer* can be readily extended to an arbitrary number of participants who can collaboratively control the system, linked over the Internet using the Open Sound Control (OSC) protocol. Conversely, *MoodMixer* can also currently be used by a single individual, with audio represented in either the four-channel surround sound configuration or collapsed to stereo for portable use.

Although the reported instantiation of *MoodMixer* uses Neurosky's measures of focus and relaxation, future instantiations may incorporate EEG-based measures of affective state, such as emotional arousal ("active" vs. "calm") and valence ("positive/good" vs. "negative/bad"). Recent research performed on human subjects listening to short music pieces [5, 4], has shown that changes in self-reported emotional arousal and valence induced by listening to music pieces, as well as tempo (fast/slow) and mode (major/minor) of listened music, is significantly correlated with changes in EEG bandpower. Specifically, it was found that listening to minor mode music was correlated with increased frontal midline gamma power (25-60 Hz) while the converse was true for major mode music. Additionally, listening to slow-tempo music correlated with increased theta (4-8 Hz) activity. Furthermore, in a related study using the same music dataset, positive emotional valence was positively correlated with theta power and negatively correlated with delta power, while emotional arousal was positively correlated with both delta and theta power [5]. A recent study by our colleagues Onton and Makeig demonstrated that EEG features associated with 15 prototypical emotional states (Joy, Love, Frustration, ...), when mapped onto a two-dimensional plane using non-metric multidimensional scaling (MDS), formed a circumplex pattern with features corresponding to similar emotions located near each other in the MDS space, and negative valence emotions arrayed on the left and positive valence emotions on the right [10]. A natural extension of *MoodMixer* would allow participants to emotionally navigate a similar two-dimensional audiovisual space, wherein music tracks associated with each of a number of affective states are each assigned a corresponding coordinate in the transformed MDS space and continually mixed based on the participants' positions in the transformed MDS space. Future generations of the *MoodMixer* design may also incorporate algorithmic composition techniques to generate a musical "mood" mixture in real time which corresponds with the participants' affective or cognitive states.

Accurate detection of many of the aforementioned complex cognitive and affective states likely requires recording of signals from multiple brain regions. While our current instantiation of *MoodMixer* uses a single-electrode wearable EEG system, which is suitable for inferring basic states of arousal and cognitive load, the use of a multichannel system would provide data from more scalp locations allowing for calculation of interhemispheric differences as well as enabling robust spatiotemporal source separation techniques, such as Independent Component Analysis which can dramatically improve the signal to noise ratio and interpretability of the acquired data [7, 2]. This in turn would expand the range of cognitive and affective states that can be monitored for control of the system. Fortunately, wearable multichannel EEG hardware is now becoming ubiquitous with a number of established and nascent companies offering affordable multichannel "dry" (gel-free) electrode systems (Emotiv, Quasar, BrainProducts GmbH, PICO imaging, g.tec GmbH, to name a few). We are currently experimenting with a 16-channel wearable EEG system and plan to incorporate this technology into future instantiations of the installation.

Our use of wearable, wireless EEG technology introduces additional practical applications of *MoodMixer*. For instance, it may be used as a single-player or collaborative game in which players attempt to actively manipulate their cognitive or affective states to produce different musical/visual mixtures. Or it might be used as a computer desktop gadget/widget or mobile phone app in which an aesthetically-pleasing "background" electronic music mix (with optional visual texture) is continually generated based on passive monitoring of the user's mental state as they go about their day. Such a system may even have therapeutic applications, for example allowing one to inobtrusively monitor their own levels of stress or relaxation throughout the day. There are a number of possibilities, and we hope that this and other extensions of the *MoodMixer* concept will expand the existing repertoire of fun and aesthetically-pleasing systems for individual or collaborative, passive or active cognitive/affective sonification.

4. CONCLUSIONS

In this collaborative EEG sonification system, two participants control a music mix and corresponding visualization by actively or passively manipulating their cognitive state. This approach is novel in its collaborative design, and in that it affords both active and passive sonification approaches. *MoodMixer* represents a first step towards new media projects which explore new modes of social interaction and affective processing and control in brain-computer music interfaces.

5. ACKNOWLEDGMENTS

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