Exposing the Brain Activity in an EEG Performance: the Case of *Fragmentation – a Brain-Controlled Performance*

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Abstract. Most brainwave-based performances adopt spectral decomposition of the EEG signal into several frequency bands to control different sound-synthesis variables. The performer is stable, usually sitting in a meditative way. It is rather difficult for the audience to determine what the performer is actually controlling and in which way. Traditionally, the audience witnesses a performance based on the telekinetic dream of brain-control but yet this is not externalized in an objective way. I believe it is possible to extend these performative limits by using a gamification paradigm and developing analytical tools that go beyond spectral analysis, allowing a more responsive and clear control of the variables involved in the performance for both the performer and the viewer. In this paper I present the qualitative results obtained using these approaches in *Fragmentation – a brain-controlled performance.* From the informal feedback of the audience after the performance, it appears evident how the public is able to experience several aspects of the brain of the performer: predicting his intentions, sensing effort and struggle, and spotting his mistakes. These aspects create a strong experience and involvement for the audience during the performance.

Keywords. brainwave, EEG, audiovisual performance, bio-feedback, cross-correlation, time-analysis, gamification.

1 History of Brainwave Performances

Since the discovery of electric pulsations arising from within the human brain, imaginative souls have speculated that internal realities would eventually be shown externally and materially manifest through a direct connection of the brain to devices for sound production and visual display. The connection of the brain with engines or actuators gives the idea to have telekinetic control at hand’s reach. In the early 50's this dream seemed particularly close and the first experiments of brainwave music started [1, 2, 3, 4]. The main objective was to dematerialize the musicians' instrumental gestures and use their brain signal to let the performer control some aspects of the music performance with their mind. Since then many experiments have followed [5, 6, 7, 8, 9, 10, 11, 12].

In most of the past and recent brainwave performances, the performers lie with some EEG sensor on his their head, in a static pose, while music is played from loudspeakers [1, 7, 12]. Despite the claim that the music is controlled from the brain activity, and the initial intentions to manifest the internal realities of the performer, it is hard for the audience to imagine what the performer is going through, what the brain is actually controlling and in what extent. As a direct consequence of the dematerialization of instrumental gestures, the music produced is completely abstracted from any visible cause-effect relationship, leaving no cues for the audience to understand what is being controlled.

The way control is achieved is a fundamental aspect of every brainwave performance. Past performances principally used the electro encephalogram (EEG) signal and its different bands (alpha, beta, delta gamma) to control different parameters of the sound synthesis (spectral analysis) [1, 2, 3]. Alvin Lucier was the first to use the EEG signal in a music context in his *Music for Solo Performer* (1965) [4]. The alpha waves of the performer at 12 *Hz* were amplified enormously to create large vibrations in the loudspeaker cones, which were coupled with gongs and drums. The brain signal of the performer was in this way amplified to play an entire percussion set. With *In Tune* (1968), Richard Teitelbaum used a different approach: the signal of the brain activity of a performer was fed into the architecture of a Moog synthesizer's, thus letting the EEG signal directly modify few sound parameters, while the composer could freely improvise with higher structural decisions. Alpha and beta waves were used for their simplicity to be extracted from the background spectral noise [2]. In the 70s, Rosenboom analyzed the possibilities and limitations of the extraction of features from an EEG signal for the purposes of modeling brain functionalities towards a conscious control of generative music rules and formalized such investigation in several papers [11]. In particular, he focused on the time features of brain signal: through at-the-time established psychological practices, he realized that stimuli would consistently produce attention peaks in the brain signal after predictable time intervals. He could use an estimation of the performers' attention to control the compositional development of the performance.

Because of the complexity of brain analysis and Rosenboom's approach, contemporary practice [5, 6, 7, 12] still follows the early examples of brainwave performance and relies on spectral decomposition in performances. The results are often difficult to understand and visualize for the audience. Contemporary literature [10] shows how this result is a consequence of the difficulty for the performers to rationally control their brain spectrum. In recent years Miranda underlined in several papers the fundamental importance that extracting meaningful descriptors from the EEG signal has for the purpose of extending the expressive possibility of EEG in music improvisation [8, 9, 10] and the need to extend the analytical tools beyond standard spectral analysis. Despite the suggestions of analytical methods and strategies for a more direct and reliable brain control, the approach of Miranda has only been published in papers, and its practical demonstrations seem still expressively limited to be adopted for an extended performative application [9].

My recent research addressed the EEG's issues of direct control and performativity in order to achieve a deeper involvement of the audience during a brainwave-driven performance. In *Fragmentation: a brain-controlled performance*, I adopted artificial-intelligence algorithms using cross-correlation to:

- train the system: by storing in a set of templates the signal of brain states associated with specific thoughts,
- measure the likelihood that the incoming signal of the performer during the show is matching one of the stored templates.

2 Present Approach: *Fragmentation – a Brain-Controlled Performance*

The performance is an allegory of the modern man: exposed to aggressive stimulation and overwhelming data streams, he is daily asked to take quick decisions and be able to switch from several environments, in which he plays different roles subjected to varying rules and degrees of responsibility. The aim of the piece is to let the audience experience different degrees of mental stress, stimulation and saturation through a physiological live-scan of the performer's brain, exposed to few extreme but common everyday situations. In this way, *Fragmentation* tries to bring the audience deeper in contact to the performer's brain through the exposure of his mind activity in form of individual thoughts. Throughout the piece, music and visuals are used in various ways to become a translation (a sort of visual-sonification) of the brain activity.

On a technical point of view, my approach is a continuation of Rosemboom's early experiments and Miranda's proposition. Instead of using spectral decomposition, which has proven to be difficult to rationally control by the performer, the techniques utilized in *Fragmentation* investigate the temporal domain of the brain signal. The main idea is to observe when a pattern reoccurs in the brain signal. If thoughts have a consistent translation into an electrical impulse, then repeating thoughts would generate electrical patterns, thus signals. Hence, analyzing pattern reoccurrence is a way of tracking reoccurring thoughts. The chain could be reversed: the performer could be trained to generate thoughts in an exact way and the system could be trained to recognize those at every instance.

The first important step of pattern recognition is the extraction of reliable patterns for matching. Patterns are calculated by asking the performer to concentrate on specific thoughts, while recording EEG inputs. From the spectral analysis of the signal, onsets are detected to isolate relevant parts. Because noise is uncorrelated by definition, while the signal is not, adding several of the signal parts creates a destructive interference of noise and strengthens the relevant parts, thereby letting the relevant signal emerge. It took several attempts to find the proper set of *'thoughts'* that triggered reliable brain states; especially stable are *'kinetic thoughts'*: e.g., imagining moving specific parts of the body, such as left and right limbs.

Cross-correlation was used to compare how much the incoming signal matches the set of pre-stored patterns in the system. Cross-correlation is a measure of similarity between two waveforms as a function of a time lag applied to one of them. It is commonly used for searching a long-duration signal for a shorter, known feature. Considering two waveforms *f* and *g*, where *f* is the short stored pattern and *g* is a longer signal representing the real time samples of EEG, the cross-correlation at the sample *n* would be:

$$(f * g)[n] = \sum_{m=-\infty}^{\infty} \overset{\Delta}{f}[m] \cdot g[n+m] \tag{1}$$

where *n* and *m* are sample positions and $\overset{\Delta}{f}$ is the complex conjugate of *f*.

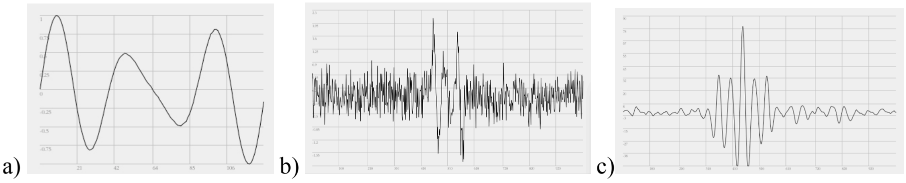

Fig. 1. Examples of cross-correlation, where the x−axis represents time in samples and the y − axis amplitude in arbitrary units: a) example of the wanted pattern signal, b) example of a similar pattern immersed in a noisy signal, c) cross-correlation of the two signals. The reader can observe a peak in the center determining the position of max correlation and detection of signal b).

This pattern-recognition approach through cross-correlation demonstrated to be relatively solid but very restrictive. The performance of the system was evaluated on the recognition of three thoughts out of 100 trials. The system could correctly recognize 60% of the generated thoughts. However the algorithm was very unstable when trying to identify more than three thoughts. As a consequence, the whole system had to be conceived with direct control on only three variables; and because from a signal-detection perspective it is unclear what is a combination of two thoughts (and it is still debatable whether it is possible for humans to generate two thoughts simultaneously), the system could detect changes in only one variable at a time. It became immediately evident how important for the performance was the choice of the mapping strategy: to reliably connect three variables to generate music parameters and still achieve a reasonable degree of expressivity for the performer.

3 Mapping

The mapping of the control variables was conceived to achieve both a visible and reliable control of the sound engine while allowing the performer to control several high-level parameters of the composition. I followed two directions, by splitting the signal analysis chain in two parts. The first part could sample in real time parts of the brain signal and loop them to create a direct sonification of the brain. I call this the soloist brain and it's activated in specific parts of the structure of the piece.

The second approach aimed at achieving a control on the overall structure of different stochastic instruments. I called this the brain-conducted orchestra, accompanying the soloist brain. For this approach I used the previously described techniques of pattern recognition to reduce the possible control variables from the complex input sensor data to three variables. I then used the paradigm of terrain exploration: the performer drives an avatar through a computer-generated maze in search for the exit, in a video-game paradigm. The performer uses three thoughts to turn left, turn right and move forward the avatar. The maze is simultaneously projected on screen for the audience and onto stage for the performer so that he can physically follow his avatar while performing. The visuals projected onto the performer and stochastic music loops are triggered and modified by the avatar's position in the maze. The time and structure of the composition is thus entirely determined by the choices and concentration of the performer. Despite the distracting surroundings, the glitchy sound and flickering visuals, the performer must remain paradoxically calm in order to generate the correct states of mind that would let him navigate his avatar out of the maze.

This approach introduce a convergent mapping that brings simplicity of control, which is required to stabilize the intrinsic noisiness of the EEG. Still, in order to obtain some expressivity, I needed to map the few control parameters to the multiple synthesis and structural parameters in the music through a divergent mapping. The result is hybrid mapping in which the pattern recognition is an intermediate phase to clean the signal from noise and select few stable control parameters.

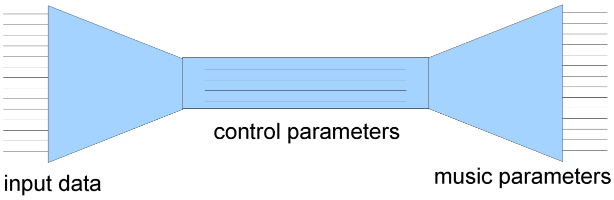

Fig. 2. Scheme of the hybrid mapping used. The complex input data is reduced from the sensor input to the few control parameters and expanded again using divergent mapping to achieve expressivity.

4 Conclusions

The use of time analysis allows the performer to rapidly and reliably control the avatar with his brainwaves. The system is also quite rigid in nature, allowing the control of only three variables non-simultaneously. This aspect imposes heavy restrictions on the expressivity and conception of the piece. A degree of noise is present in the system, making the task of the performer more difficult. Future improvements of the hardware and software can reduce the present noise to create a solid system for brain control. The system is still quite basic in the number of variable that can be controlled and future studies are needed to investigate on how to extend such limitations. The ease of control compared to spectral approach allows a more direct display of the procedures, which generates a higher involvement of the audience. The feedback from the public demonstrates the success of such intention, as interviewed members have declared they could perceive the intentions of the performer, his mistakes, effort and struggle, thus contributing to form a stronger experience and involvement during the performance. Such effect is not only produced by the analytical tools used in the performance, but it is also conveyed through the video-game paradigm used for the performance.

Links

`http://www.jestern.com/`

`http://vimeo.com/jestern/fragmentation1`

References.

1. Lucier, A. (1995). Reflections, Interviews, Scores, Writings, 1965-1994. Musik- Texte.
2. Zimmerman, W. (1976). Interview with Richard Teitelbaum in Desert Plants: Conversations with 23 American Musicians. Aesthetic Research Centre of Canada Publications, Vancouver, B.C., Canada.
3. Rosenboom, D. (1984). On being invisible: I. the qualities of change (1977), ii. on being invisible (1978), iii. Steps towards transitional topologies of musical form (1982). Musicworks, 28, 28:10–13.
4. Lucier, A. and Simon, D. (1980). Chambers. Scores by Alvin Lucier, Interviews with the composer by Douglas Simon. Connecticut: Weslayan University Press.
5. Chechile, A. A. (2007). Music Re-Informed by the Brain. PhD thesis, Rensselaer Polytechnic Institute Troy, New York.
6. Filatriau, J. J. and Kessous, L. (2008). Visual and sound generation driven by brain, heart and respiration signals. In Proceedings of the International Computer Music Conference.
7. Robels, C. (2012). Personal website. http://www.claudearobles.de.
8. Miranda, E. R., Sharman, K., Kilborn, K., and Duncan, A. (2003). On harnessing the electroencephalogram for the musical braincap. Computer Music Journal, 27(2): 80–102.
9. Miranda, E. R. and Brouse, A. (2005). Interfacing the brain directly with musical systems: On developing systems for making music with brain signals. Leonardo, 34(8): 331–336.
10. Miranda, E. R., Durrant, S., and Anders, T. (2008). Towards brain-computer music interfaces: Progress and challenges. Proceedings of International Symposium on Applied Sciences in Bio-Medical and Communication Technologies.
11. Rosenboom, D. (1990). Extended Musical Interface with the Human Nervous System, Assessment and Prospectus. Leonardo Monograph Series: International Society for the Arts, Sciences and Technology (ISAST).
12. Haill, L. (2012). Tunes on the brain: Luciana Haill's eeg art. Retrieved March 15, 2011 from http://www.wired.co.uk/magazine/archive/2010/09/play/tunes-brain-luciana-haill-eeg-art.