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EEG-based Real-time Audio Generation and Interaction

Cătălin CREȚU[1]

Abstract: *The paper explores, in a contemporary manner, dynamic and interactive ways of triggering, generating, and transforming sound using an electroencephalograph. It describes the methods, musical strategies, and specially designed algorithms, illustrating the possibilities for creative approaches in artistic endeavors – stage music and performance – from the author's work.*

Key-words: *EEG sonification, algorithmic composition, BCI, interactive music*

1. Introduction

In the field of music, electronic media can be used interactively in many ways. Among the techniques based on new technologies, possibilities such as triggering audio processes, algorithmic control, or real-time transformation of sound parameters stand out. This paper aims to identify these types of interaction and provide a brief description of the algorithms used in two of the author's works, which use measurements of electrical brain activity as input data.

The first project, inter@FAȚA[2] – interactive stage music – was based on the idea of creating a theater performance that addresses the issue of discrimination in contemporary Romanian society. To generate sound, the team used two 14-channel Epoc X[3] EEG headsets designed to monitor subjects based on electroencephalograms – one worn by an actor and the other by a volunteer spectator. As part of the project, a BCI (Brain Computer Interface) was designed and implemented to evaluate and exploit the emotional parameters of the participants for artistic purposes: first musically, then choreographically, and finally for lighting control.

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[1] National University of Music Bucharest, catalin.cretu@unmb.ro

[2] For the musical strategies of the project see „EEG-based Interactive Stage Music". *Information and Communication Technologies in the Musical Field* VI (2): 83-91. https://tic.Editura mediamusica .ro/reviste/2015/2/ICTMF_ISSN_2067-9408_2015_vol_6_issue_2_pg_no_83-91.pdf

[3] https://www.emotiv.com/products/epoc-x

Although the same algorithms were used to create music in real time using Max[4] software, each performance generated distinct music based on different emotions, which led to the formation of classes of compositions. This paper focuses on the musical creation part of the show, with details on the working method and aspects related to emotion prediction being covered in the article *Extending Performativity through a BCI Interface*[5].

In the second project – Do your music through my brain[6], performance – a 5-channel EEG Insight headset was used to monitor the performer's brain activity, and the data obtained was transmitted to a parametrically controlled synthesizer via a specially designed interface.

2. Musical strategies

The sonification methods and strategies[7] were designed considering the type of data coming from the EEG headset electrodes and the values shown in the graphs of the emotions generated by them. The composition algorithms used covered a broad conceptual area, appealing, depending on the context, to various instances of the four techniques/categories described at the ICAD 2013 conference[8]: audification (direct control of parameters such as frequency or amplitude), association of numerical parameters with musical data (control of pitch, tempo, duration), sonification based on acoustic models (sound synthesis), generative processes (dynamic modification of musical timbre based on wavetable synthesis).

2.1. Audification techniques

The *sinusoids~* object, a bank of sinusoidal oscillators produced at CNMAT[9], is at the heart of the first method of transposing numerical data from the helmet electrodes into sound. Twelve initial data points are used, transformed into frequency-amplitude binomials and organized into four groups of three, which, when superimposed, generate musical structures similar to sinusoidal microclusters. These are played in turn, their selection (one binomial out of four)

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4 https://cycling74.com/products/max

5 https://www.dramatica.ro/index.php/j/issue/view/14

6 https://www.youtube.com/watch?v=Ax2nUxzi4sk

7 For the background and description of EEG sonification, see Miranda

8 See Väljamäe, Aleksander, Sebastian Mealla, Tony Steffert, Simon Holland, MarimonXavier, Raul Benitez, Oliveira Aluizio, and Jordà Sergi.

9 www.cnmat.berkeley.edu/MAX/

and audio on–off activation being controlled by the actant's emotion. Both functions are managed by the *trend-report* object, which detects the direction of the ascending or descending numerical flow (1/–1) (Figure 1).

The parameters obtained from the 12 electrodes of the headset are involved in white noise resonance processes (Figure 2) — the second hearing technique. This time, in addition to the frequency-amplitude binomial, a new factor comes into play: the decay rate. For this type of process, the *resonators~* object was used, which was also developed by the CNMAT team.

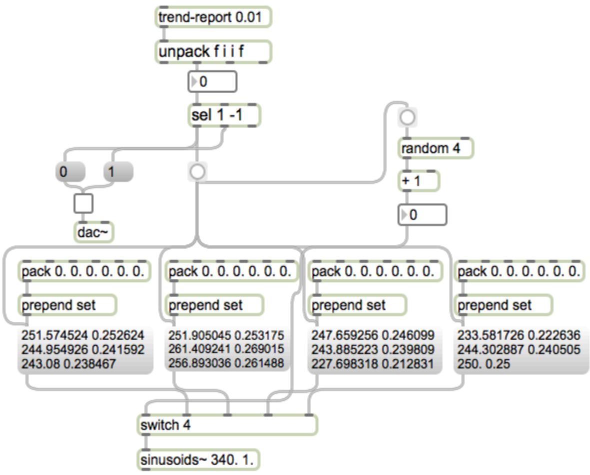

Fig. 1. *Sinusoids*

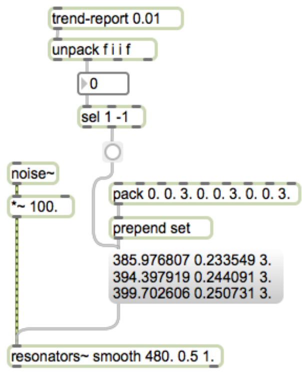

Fig. 2. *Resonators*

The purpose of the third audification technique is to generate a spectrum of 14 harmonics for a virtual fundamental sound. One of the emotions determines the base frequency, and the 14 harmonics are organized into two groups of seven: even (harmonics 4, 6, 8, 10, 12, 14, 16) and odd (harmonics 3, 5, 7, 9, 11, 13, 15). The amplitude of each sound in the spectrum is dynamically adjusted according to the numerical values obtained from the variations of the 14 electrodes of the headset. The panning of the two spectral states generated by the sound entity is controlled by the difference between the values of two selected sensors, 0 representing the left channel and 1 the right channel (Figure 3).

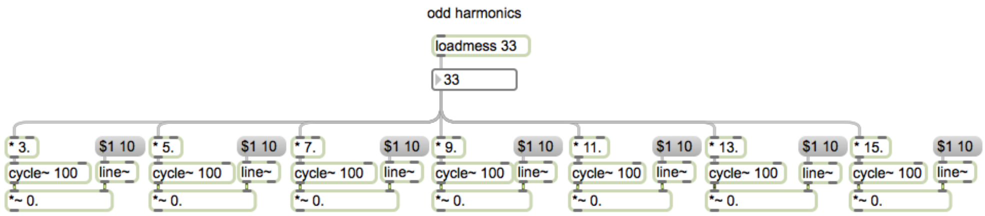

Fig. 3. *Spectrum*

2.2. Associating numerical parameters with musical data

Basically, the musical accompaniment is based on an ostinato rhythmic structure, consisting of sequences of perfect fourths and fifths, chosen at random and played on a virtual instrument; its tempo is determined by the curve of one of the emotions (Fig. 4). This structure is overlaid with a melody that accelerates and rises in the high register, proportional to the increase in the values associated with another emotion. The harmonic structure is reinforced by variable and consonant intervals (minor and major sixths), with a length of 3-5 seconds, with the base chosen randomly within an octave range, controlled by another emotion.

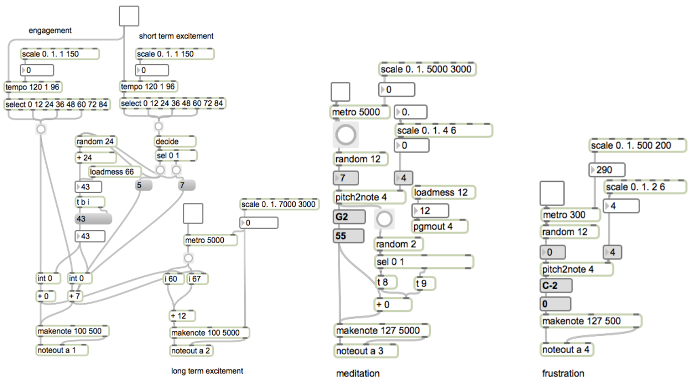

Fig. 4. *Accompanied melody*

2.3 Sonification based on acoustic models

The techniques used here refer to the creation of sound syntheses based on EEG data. The moment when the polarity of the alpha waves changes from the left hemisphere to the right is marked by short sounds (100 milliseconds), cut from an ostinato continuum based on a slightly modified 5 Hz sawtooth sound (Figure 5).

One of the emotions is associated with the tempo of the pulse, which is expressed sonically by changing the frequency of the pure sine wave carrier between 1-3 Hz, another emotion produces a timbral change by varying the amplitude of the modulating sine wave, generating together an FM-type synthesis, which is then applied to the four fundamental types of sounds (sine, sawtooth, triangle, rectangle), mixed using EEG parameters (Figure 6).

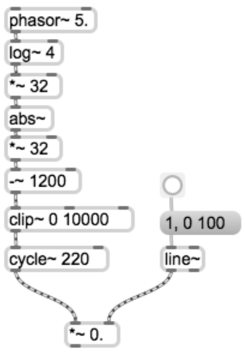

Fig. 5. *Sawtooth*

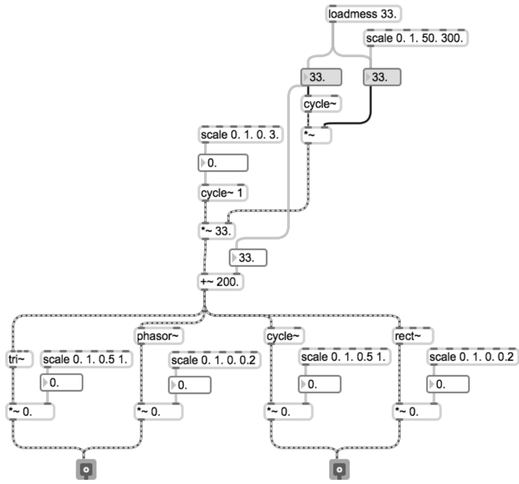

Fig. 6. *FM-type synthesis*

2.4. Generative processes

The process described in Figure 7 transforms the currents recorded by the 14 electrodes into numerical data, which, through the algorithm in Figure 8, simultaneously generates melodic contours and sound timbre, all dynamically modified in real time. The melodic contours are created by traversing the *index~ melody* using *phasor~,* and the timbre results from the continuous modification of the 14 sound fragments (samples) taken from the *wave~* object through *buffer~*.

One of the emotions controls the tempo and register of the melody, as well as the timbral mix. When this value increases, the melody accelerates, rises in pitch, and – for values above 0.5 – the timbre changes, with a component resulting from its ring modulation with the wavetable synthesized sound through the *wave~* melody object being added to the initial sine wave.

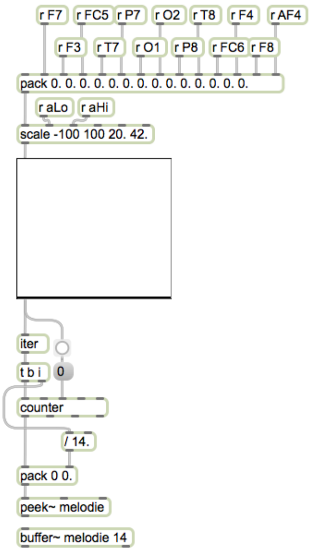

Fig. 7. *Buffer*

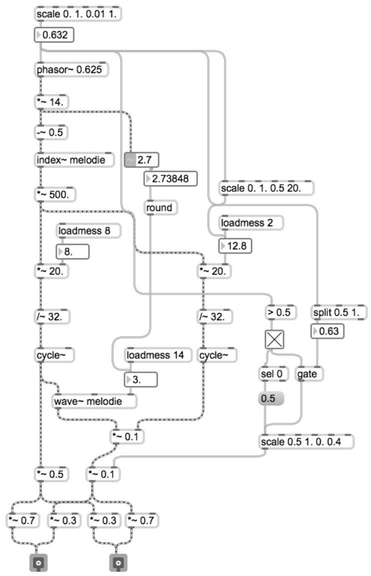

Fig. 8. *Melodic contours/sound timbre*

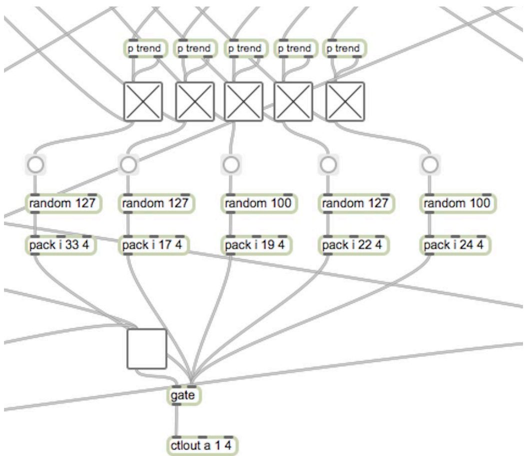

Fig. 9. *Trend-report control*

In the performance *Do your music through my brain*, each brain wave, captured by an EEG headset, controls 25 parameters of a synthesizer in real time, using the algorithm described in Figure 9. The EEG graphs are taken over by trend-report objects – similar to the one shown in Figure 1 – as follows: the ascending direction

(1) triggers the sound process, and the descending direction (-1) stops it. Each sound is based on two oscillators, controlled by selecting the waveform, their pattern, and the mix between them. The result is a complex sound, consisting of five acoustic entities modified dynamically in real time, all directly influenced by the performer's brain activity.

3. Conclusions

The originality of such approaches is reflected in the way BCIs and related software are designed, developed, and used to integrate constantly changing music into an artistic act, controlled in real time by EEG, their dynamics being determined by the involvement and experience of the audience or performer.

Starting from the novel ways of generating music proposed, increasingly complex approaches can be initiated, which capitalize on the potential of contemporary technology. Hybrid electroacoustic projects that integrate new technologies can be approached in a flexible framework, allowing for the development of sound processes that would be impossible to achieve in the purely acoustic world, while also generating possible echoes in the visual and multimedia fields.

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