Creating a Place as a Medium for Musical Communication Using Multiple Electroencephalography

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ABSTRACT

Music is an activity that expresses human thoughts and emotions, for which human brain takes a central role. Meanwhile, music offers an emotionally compelling experience when multiple persons lively participate. We hypothesize that brain activities would exhibit specific responses and patterns to music in a situation where multiple persons gather and perform the music. Upon these premises, we created an installation piece, which attempts to represent the interconnection of people's minds by capturing the characteristics of brain activities associated with music. The system for the installation handles Electroencephalography (EEG) data acquisition, data analysis, sonification, and visualization. The system analyzes EEG of multiple participants when they respond to given stimuli, such as acoustically played musical notes or simple visual elements. The result of spectral analysis and the averaged responses of brain activities of all the participants are represented with musical notes and visual images. The system has been devised to be compact and reproducible by making good use of devices that are commercially available. With this system, we created an installation piece focusing on the human brain to constitutively form a space where musical communication arises.

1. INTRODUCTION

We developed a system for an installation piece to produce sonification and visualization of the analyzed brain activities of multiple participants responding to visual and auditory stimuli (Figure 1). Using this system, we created an art installation piece focusing on the human brain with an attempt to constitutively form a place where a primitive form of musical communication arises [1] .

Figure 1. Picture of our installation piece with 3 participants. at Tokyo University of the Arts.

As described in Section 1.2, many art works using Electroencephalography (EEG) have been realized. Arguing the novelty of our project might be difficult, yet our work is distinct with the following aspects, delivering unique experience to the audience: (1) the sonification and visualization of both individual and collective data, (2) the concurrent sonification of both EEG spectral analysis and ERP (Event-Related Potential) response, (3) the straightforward audiovisual mapping with minimal data processing, that allows participants to directly attend data, (4) the electro-acoustic aspects of Clarinet and EEG composition.

In this paper, we describe the background, concept, and development of our work.

[1] This installation piece is submitted to Joint ICMC - SMC 2014

1.1 Basic Concept of Installation: Musical Communication

In many cases of music, more than one person congregates in a given place. The musicologist Charles Small proposed a concept of musicking, meaning any activity involving or related to music performance [1]. He also argued that the act of musicking establishes a relationship of all individuals contributing to the nature of an event that is a musical performance, in any place [2]. In such a situation, interactions between individuals are orchestrated within a single brain, according to Benson [3].

Building from this idea, we are currently developing an art piece in the form of installation with multiple participants. This is because we intend to capture the characteristics of brain activities associated with music that are present not only in the brain activities of individuals, but also in the relationship between the brain activities of multiple people. Besides that, we also assume that brain wave patterns specific to music appear more strongly in a situation where multiple persons gather and perform the music. Therefore, we decided to compose an expression of this phenomenon by extracting the internal states of individuals and their interconnection using EEG.

1.2 Related artistic works using EEG

EEG is a technique used for over a century to measure electrical changes along the scalp in order to record brain activity. It is used not only in the medical and research fields, but is also used as a tool for many artistic works. The most attractive aspect is that the EEG may reflect thoughts and emotional states. In recent years, some portable EEG systems have become available on the commercial market.

Many artists are attracted to the use of EEG for their pieces. The composer Alvin Lucier is known as the first person to produce music with an EEG [4]. David Rosenboom adopted an approach of biofeedback processes during musical performances where he made the brain state of the performer audible [5].

These works still have an influence on art projects in recent decades. In a series called DECONcert, the EEGs of 48 participants are used to produce biofeedback [6]. The MiND Ensemble, gives stage performances using a portable EEG system [2]. There are also some notable projects that employ multiple EEG systems associated with two-dimensional representation of emotion, based on valence and arousal model [7], or relaxation and attention framework [8].

1.3 Brain dreams Music Project

The brain takes a core role in human activities including music, and music can be considered as an act inseparable from human thinking and emotion. Around the year 2010, we started a new project. We aimed to holistically capture the various aspects of music by tracing back to the stage at which music, emotion, and other thoughts are undifferentiated in human brain.

[2] The MiND Ensemble http://www.themindensemble.com/

On that idea, *Brain dreams Music Project* was founded in 2011 [3]. The project aims to bridge art and neuroscience, and explore a new form of musical instrument. The project is both conducting research on how brain activities relate to music, and developing artistic works such as live performances and installations. The project is organized by members from many domains such as composers, visual artists, neuroscientists, computational scientists, engineers, and others.

1.3.1 Fundamental Research and Technology

Since the establishment of the project, we have developed a technology for artistic expression by connecting the EEG with sonification and visualization. In the early stages of the project, we have focused on the EEG activity of individual people during their imagination of music. As an basic research study, Hoshi-Shiba has succeeded in finding the neural correlates of expectation of termination, while listening to a dominant chord in musical termination structure or cadence [9]. Currently, we are further investigating the neural activity of music imagery by applying similar experiments to both the listening of music and recalling music in one's mind. We are planning to publish the result of this study this year.

1.3.2 Development of "it's almost a song.."

Based on the results of the above research studies, we developed a musical instrument using brain-computer interface (BCI) technology to generate an integrated musical expression [10]. We developed a real-time musical performance system using a classification technique in BCI technology[11] and sonification techniques to generate chords with organically fluctuating timbre. The concert piece "it's almost a song..." is performed with clarinet, or with string quartet.

In this paper, we present the installation version of "it's almost a song..." that inherits the core real-time technologies such as data acquisition and analysis, visualization, and sonification, from "Brain dreams Music Project". The installation version was first presented at a workshop in Fukushima, Japan in summer 2013. This manuscript describes the most current states of the installation version.

2. DESCRIPTION OF THE INSTALLATION

"it's almost a song..." installation version is for three Electroencephalography (EEG) systems and Clarinet. The mixture of musical, auditory, and visual stimuli and the real-time visualization/sonification of EEGs by audience comprises a spatial and interactive representation of interconnected musical minds. Three participants from audience listen to a clarinet composition, or observe visual stimuli (flashing geometric figures), and provide their brain activities via EEG. The measured brain activities are sonified and visualized, resulting in the following elements of the installation:

[3] Brain dreams Music http://brain-dreams-music.net/

Audio

- Continuous musical notes of harp whose pitch is mapped from the averaged alpha-band power from each participant. "Melodies" contributed from multiple participants comprise an auditory stream, forming a collective audio representation.
- Musical notes of marimba as a time-scaled playback of ERP where the averaged voltage is mapped onto the pitch. Collective representation of the neural responses.
- Clarinet composition, to artistically stimulate music-related brain activities.

Visual

- Raw EEG wave forms from 14 electrodes for each participant.
- Spectrum (frequency analysis) of EEG from 14 electrodes for each participant.
- ERP wave forms for each participant.
- Sparkling visual objects by alpha-band power for each participant and for averaged result. (showing individual and averaged result)
- Animated overlapping rings by ERP. (showing individual and averaged result)

This installation system aims to display the brain activities of multiple people with visualization and sonification and to build an environment to share it with an audience. We aimed to build a compact and reproducible system with the aid of devices that are commercially available.This system is not a BCI per se, but rather an interface for a constitutive experiment in order to develop a place that allows musical communication. In the latest version of this work, three participants wear EEG equipment. We have succeeded in running our developed system with five participants, and handling data from more participants is feasible, in theory.

3. IMPLEMENTATION

3.1 Design of Architecture

We designed the architecture of the installation system as shown in Figure 2. The system consists of input sources including the EEG system and sensors, many software process units for individual participants and for the integration of their results, and equipment for their output as well.

3.1.1 Input Sources ([A])

Stimuli are given to the participants while their brain activities are measured. There are two kinds of stimuli, audio and visual image. For the auditory stimuli, musical notes are played by an acoustic instrument such as a piano or clarinet. For the visual stimuli, a pre-composed movie, like the flashing of simple shapes with a vivid color, is projected on a monitor and a screen. The timing of both of the stimuli are detected with *Onset Detector* and *Photo Detector* as described later.

3.1.2 Software Units for Individual Participants ([B])

When the system is started, software units for EEG processing and visualization for individual participants are launched automatically. The number of these units is determined by the number of the participants. *EEG Receiver* processes the acquisition of EEG and two kinds of analysis. This program is written purely in C for the sake of processing speed and time precision. The result of the analysis is sent to the *Visualizer*. *Messaging Server* assists interprocess communication and the general control of timing.

3.1.3 Software Units for Integrated Results ([C])

The analyzed data of each subject are sent to the other units for integration. *Visualizer* for the center screen and *MIDI Synthesizer* are the units with visualization and sonification as their final output. Thereby, the audience listens to the music and sees the images generated from the participants' states. Participants also perceive sonification as a form of feedback.

All programs are built in open source programming environments, such as *Processing* [4] and *Node.js* [5]. *MIDI Synthesizer* adopts *FluidSynth* [6] for real-time sound generation from SoundFont. For communication between software processes, OpenSound Control (OSC) is mainly used as a messaging protocol.

3.2 EEG System

We used a commercial gaming EEG system *Emotiv EEG* for measuring brain activity [7]. The features of this EEG system are that it is a wireless and wearable device with 14 electrodes and is relatively low-priced compared to other devices for research use. The sampling rate of the system is 128 Hz. This EEG system may prove a valid alternative to laboratory event-related potential (ERP) systems for recording reliable late auditory ERPs over the frontal cortices [12].

3.3 Methods for EEG analysis

In this installation, we used two typical methods for EEG analysis, frequency analysis and ERP. These methods are reliable and have been widely used for a long time in the history of EEG. We used them to clearly demonstrate the relationship of EEGs arising from multiple participants by keeping the analysis process simple.

3.3.1 Frequency Analysis

The frequency spectrum of EEG data was calculated by frequency analysis. The powers of each frequency band of the EEG, such as alpha and beta bands, are easily determined from the spectrum. Our system computes the spectrum for the latest time frame of EEG samples for a single second (=128 samples) at every sample for all channels

[4] Processing.org http://processing.org
[5] Node.js http://nodejs.org
[6] FluidSynth http://sourceforge.net/apps/trac/fluidsynth/
[7] Emotiv EEG System https://www.emotiv.com/

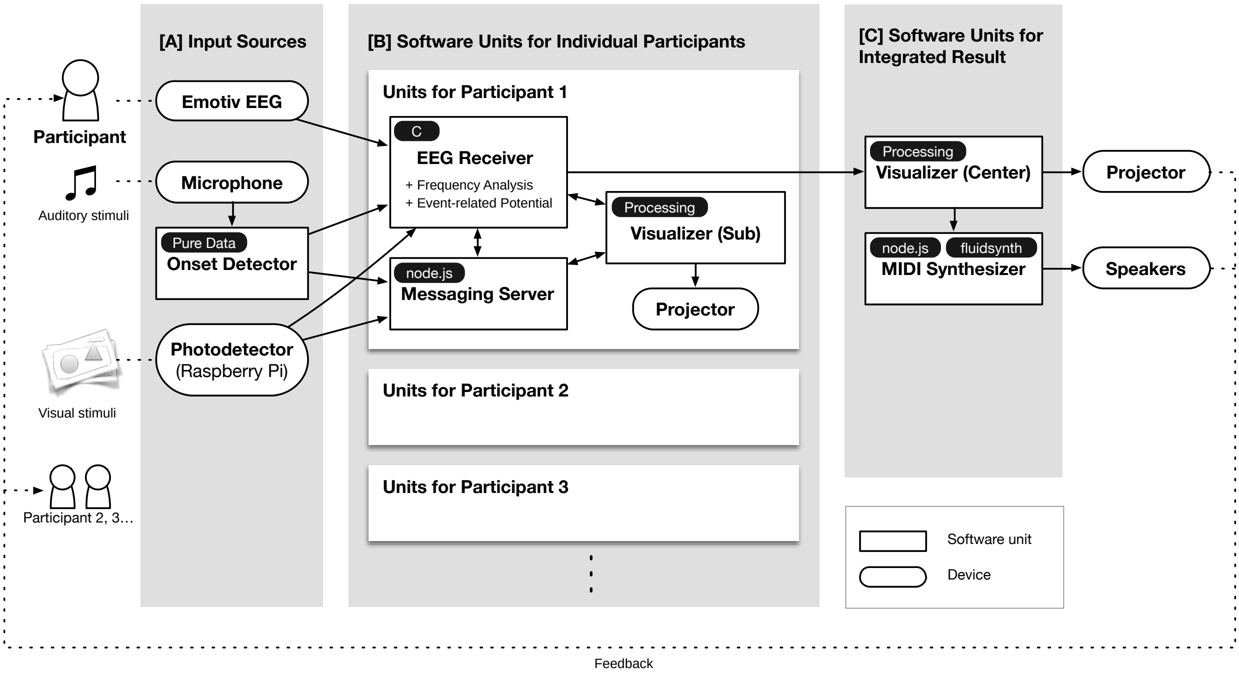

Figure 2. Diagram of the architecture of our installation system.

and participants. For visualization, the change of alpha-band power was used. We used a C library *FFTW* [8] for the computation of the Fast Fourier Transform.

3.3.2 Event-related Potential (ERP)

Event-related potentials (ERPs) are neural signals on EEG that are elicited in response to specific events [13]. We attempted to extract the ERPs for sound and visual stimuli that were perceived and shared among the participants and the audience.

When the stimuli are produced, a trigger signal is sent to the *EEG Receiver* in as accurate a timing as is possible. Our system thereafter records EEG for 1 second to the buffer after every trigger signal. The recorded samples are averaged for each channel. ERP waves are also normalized, and then the waves of all participants are averaged as an integrated result.

3.3.3 Trigger Unit for ERP

As mentioned in the section 3.3.2, the processing of ERPs should be done carefully in order to prevent time jitter. ERPs extract commonality of EEG patterns under certain conditions by diminishing noise by averaging. The responses appearing in these EEG wave forms are highly time-sensitive. Even a time jitter of a few milliseconds may destroy a clear ERP wave form.

In order to overcome this problem, we took solutions for the triggers as follows: For audio stimuli, an acoustic player makes a sound like a short pulse and the sound is sampled from a microphone. Then, the onset of the sound is detected with a program created on *Pure Data*. Meanwhile, in order to detect the visual stimuli at an accurate time and transmit the signal to the main computer, we built a trigger system based on a single board computer *Raspberry Pi* [9]. A photo transistor NJL7502L was utilized for the light sensor [10]. We employed this photo transistor because of a sharp directivity and a spectral response similar to the human eye. The trigger system is attached to a monitor and connected to the main computer with an ethernet cable.

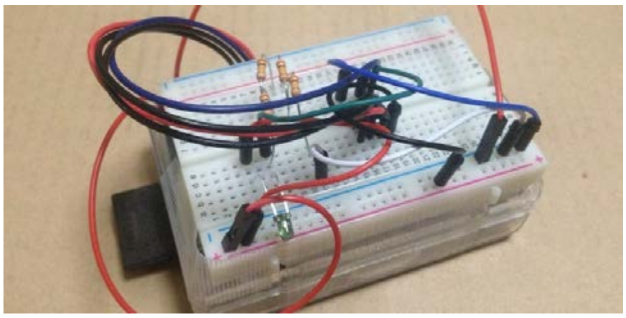

Figure 3. Prototype of trigger unit using Raspberry Pi and a photodetector.

Trigger signals of both types of stimuli are transmitted immediately to the EEG Receiver with an OSC protocol. In this way, we minimize the error of trigger times by detecting target that the participants actually perceive.

3.4 Sonification and Visualization

The results of the EEG analyses are finally converted to audio and visual images. In the current version, the parameter mapping for both the sonification and visualization is arbitrarily defined by us. This is because the number of

[8] FFTW http://www.fftw.org

[9] Raspberry Pi http://www.raspberrypi.org/

[10] NJL7502L (http://www.lanxinic.com/cn/product_2/uploadfiles/20121111154322.pdf)

musical/visual parameters is considerable, and we believe that an empirical selection may not work in this case. Thus, the parameters were adjusted to sound and look like they were expressing the most rich variety based on the data.

3.4.1 Sonification

Currently, our system allows us to generate music in two ways as a sonification from each EEG analysis result. In either manner, the resulting data is converted to musical notes that are played by the *MIDI synthesizer*.

For the frequency analysis, the relative change of the power of the alpha band averaged across all participants is mapped onto the pitch of a continuously played arpeggio of the harp. The stronger the power is, the higher the tone that is played. The note set of the arpeggio is pre-defined and the curve of the amplitude is manually configured with respect to the pitch of the tones.

For the preprocessing of ERP sonification, each data channel is normalized and the average of all participants is taken for every channel. Since the ERP data is a second long, we implemented sonification as a playback of that recorded data. Each sample of ERP data represents the normalized voltage, and it is mapped to the pitch of the tones with the marimba. It is able to change the time scale of playback, so that the result can be heard at a slower speed.

3.4.2 Visualization

The integrated results, such as the average of frequency analysis or ERP, are visualized on the screen placed at the center/top of the display. There are also other sub-screens showing the status of each subject (Figure 4). On the sub-screens, the positions of the electrodes are mapped and preprocessed raw EEG singles and spectra are depicted in real-time. Sparking objects around each electrode represents a rise of alpha-band power. ERPs are visualized like overlapping rings as seen in Figure 1. Rings represent each sample of ERP data, and their color shows time. Each electrode is mapped to the annular shape and the position of the vertices extends according to the electric potential of the ERP. This type of visualization is played as an animation associated with the sonification.

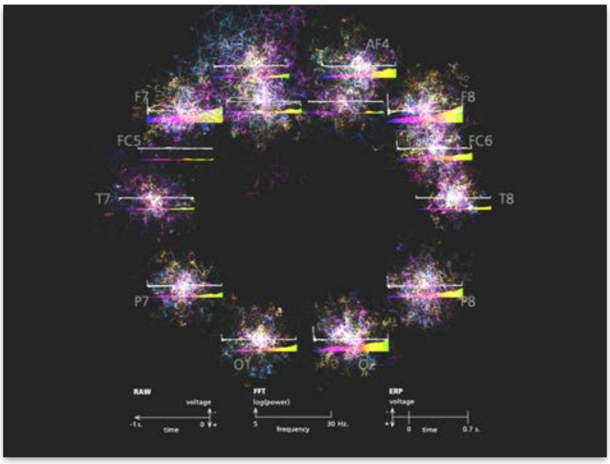

Figure 4. Screen shot of the visualization on sub-screen for one subject.

4. INSTALLATION

We conducted a workshop with an earlier version of our installation system. The workshop was held in the summer of 2013 in Affiliated Junior High School of Fukushima University. About 15 students from the university and the junior high school joined in the workshop. In the first half of the workshop, we gave a introductory lecture about neuroscience and media art, and explained about interdisciplinary collaboration in these domains. In the second half, we had time for hands-on learning session using our system. The students measured their EEG, and observed the sonification and visualization generated from the EEGs of their own. Next, we measured the ERP of five participants simultaneously and created music and images of the averaged result.

During the hands-on session, all the participants needed some time at first to familiarize themselves with the observation of their brain. However, while practicing many trials by themselves, many of them actively tried to apply various audio and visual stimuli and to see how they affect on their EEGs. When finally experimenting with simultaneous ERP, all participants wearing EEG system concentrated on the stimulus cooperatively, and that resulted in forming a very intense, focused atmosphere. After the measurement, the place was in a relaxed mood in reversal. The participants enjoyed the discussion comparing the results of everyone and their own by listening and watching the result for many times.

Currently, we are planning to exhibit our installation at various occasions to different kinds of audiences, as well as making a performance piece based on this installation.

5. DISCUSSION

Our goal is to express musical communication by multiple person in a place. Toward this goal, we developed a system enabling sonification and visualization based on EEGs measured from multiple participants. The response from the participants of the workshop was very positive in general. They lively enjoyed experimenting on their brain activities with musical or visual stimulations. The synchronization and segregation of audiovisual representations inspire the interactive exploration of the relationship between brain and music.

As a consequence of the development, we achieved to create a place which allows audience to observe a cyclical process like musical communication that music is generated from participants EEG and that music returns to participants again as a biofeedback. By representing an integrated result of multiple participants as audio and images, the audience is able to grasp the relationship among individual participants intuitively. In addition, the audience can perceive a fine change of brain activity by music as sonification which was exhaustively adjusted.

5.1 Expected Future Tasks

We have implemented two types of sonification in this system. A possible improvement will be to realize a linear mapping with real-time sound synthesis which will give more precise temporal information to the output. A Further possibility is to allow the participants to map and scale of parameters by controlling themselves. The mapping of the current version is optimized with care by the composer in order to optimize what is heard. Yet, because this is an interesting part of making this installation, participants would want to pay more attention to their brain activities if they are allowed to manipulate the mapping of their own EEG data.

In addition, we are planning to implement a real-time calculation of correlation for multiple EEGs in the next version. This feature will express the relationship between participants much more clearly.

5.2 Towards Further Experiments for Musical Communication

Different from the previous version of our work, which was a BCI musical instrument, the participants in our current work do not imagine the music directly. Rather, our installation is designed to form a place of music in a constitutive way, and to immerse the participants in that place. The acquisition of feedback such as listening to the sound and watching the visual images will enhance that means of experience.

Furthermore, our latest work only deals with a neural response to passive stimuli, while the previous work attempted to extract the proactive musical will from brain activities. Considering a situation of singing with others, it can be regarded that there is no singular subject, and occasionally the participants are identical to their group. In other words, music is not only an expression by a subject, but can be a media that connects more than one person. In this sense, the main theme of our experimental work is the human connection in music without the subject of expression, and this form of act might be the prototype of music. We will continue this exploration in order to realize and show a primitive form of music.

6. CONCLUSIONS

We developed a system for an installation piece through the sonification and visualization of EEG with multiple participants [11] . One of the long-term goals of this project is to realize a place that a primitive form of musical communication arises with the aid of neural technology, as described in this paper. The system we have achieved has allowed us to do a part of the experimental trial using products that are commercially available for that objective. We hope that it would be meaningful to share this process of development, and that it will expand to similar experimental works.

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[11] Recorded demonstration video of this installation is uploaded on the project's website.

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