# Listen to the Song of the Brain in Real Time

## The Chengdu Brainwave Music

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*Abstract*—**Electroencephalogram (EEG) provides a window for the activity of the human brain. In this work, we propose a brainwave music display system in real time—the Chengdu Brainwave Music (CBM), which translates the event, amplitude and average power of EEG into musical parameters, and plays the generated music immediately. Real EEG data is utilized as examples for the system. The system can be a useful tool for EEG monitoring, neuro-feecback, and entertainment.**

***Keywords-EEG; music; sonification; real time system***

### I. Introduction

There are many technologies including high-density electroencephalogram (EEG), functional magnetic resonance imaging (fMRI), and magneto-encephalography (MEG), which have been extensively utilized in recent years to monitor the brain activities. If the brain information could be heard through a special sonification rule, we may be able to directly "perceive" brain activity and its variation with the auditory pathway. The hearing strategy of EEG may provide not only a different real-time monitoring of brain activities but also a more sensitive way to detect the subtle variations in the amplitude and frequency of EEG that might be ignored by conventional EEG waveform technique.

Trying to hear the hidden brain activities from a noninvasive scalp EEG has a long history. The earliest attempt for translating brainwaves into music was made in 1934 [1]. A "Music for Solo Performer" was later presented in 1965 [2], and other similar music pieces followed. In the 1990s, various new music generating rules were created from digital filtering or coherent analysis of EEG [3]. However, in these early works, the mapping rules were quite direct and arbitrary.

There was a breakthrough since 2002 [4], various strategies of the conversion from EEG to audible sounds have been proposed and ample artificial sounds synthesizers are utilized for display. In resent years, there are two main categories of brainwave music systems according to the hierarchy of the features extracted for music generation, the "EEG sonification" and the "Brian-Computer Music Interface (BCMI)".

EEG sonification is the generation of artificial sounds using control by EEG data. It includes the method parameter mapping, which translates a few parameters of EEG to the characteristic parameters of music [5, 6], and event-based method which utilizes specific events such as interictal epileptic discharges as triggers for the beginning of music tones or other sound events [7]. The usual transform is based on subjectively defined translation rule [5, 7, 8]; except for the scale-free music of the brainwave we developed in 2009, which is based on the power law followed by both EEG and music [6].

The BCMI is the musical implication of the BCI, which is an interesting area for the development of new possibilities in recreational and therapeutic devices for people with physical and neuro-logical disabilities [9, 10]. In such a system, EEG frequency band and the signal complexity were used to control the music processing. In order to obtain a pleasing music, many computer music approaches were implemented in such systems.

A real time system [11] is needed for the application of the brain music method. It will be helpful for EEG monitoring, neuro-feedback, even the music performance. One important factor in such system is the musical instrument data interface (MIDI), widely used in composition and performance, with which we can obtain quite pleasing music pieces with specific instrument timbre just by inputting data to drive the interface.

As the on-line technical version of our recent brainwave music technique, introduced in this paper is the Chengdu brainwave music (CBM) system for real-time brainwave music including the data acquisition, data processing and music generation environment. The feature mapping rules are based on some intrinsic properties of waveform, for example, the amplitude, brainwave event were translated into the pitch and duration of the musical tones. We then discuss the significance of the brainwave music, and the applications of the EEG music representation in both medical and recreational fields, especially in BCI system. Finally, we present an outlook to future work to assist the exploratory data analysis and understanding the functional mechanism of brain activity.

### II. Methods

In our work, the Chengdu Brainwave Music (CBM) system, a system for real-time transformation of brain music, is designed in line with the on-line BCI system. We designed the EEG amplifier to collect EEG data, and send data to a device for data processing and music synthesizing.

This work was supported by the National Nature Science Foundation of China under Grant No. 60736029.

### A. Brain Music System

The brainwave music system is shown in Fig. 1. The EEG of the subject is collected through the electrode cap, and be amplified by the amplifier which with USB interface for communicating with the computer. The data then was sent to a message widow designed with C language in Boland C environment for processing and translation, at last, the musical parameters were sent to the MAX/MSP for music generation. The subject can see his brainwave on the screen and hear his own brain music by a loudspeaker or earphones.

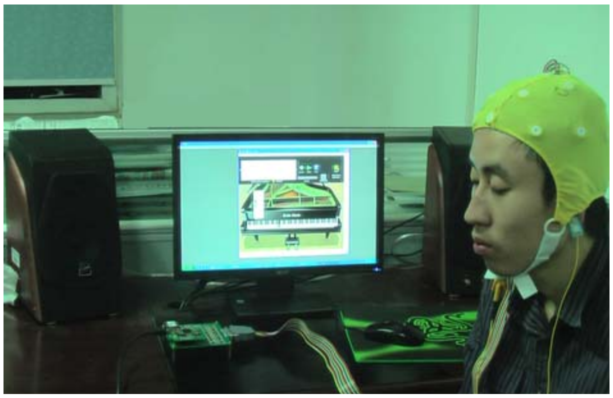

Figure 1. The brain music system in action. Shown on the screen is a virtual piano in Max/MSP.

### B. Data Acquisition

The EEG is acquired with a Lab-made EEG amplifier connected to a computer via a USB interface. The EEG data is recorded from 8 Ag/AgCl-electrodes placed on the scalp, and referenced to the earlobe. The locations of electrodes are according to the international 10-20 electrode system. The resolution in amplitude is 0.5 µV, and the CMRR>110 db. The EEG signal is sampled at 1000 Hz and digitized with a 16 bit A/D converter in the amplifier. The filters of the amplifier are set to 0.1 Hz as the low frequency cut-off and 40 Hz as the high frequency cut-off. The participant usually sat on a comfortable chair and keep quite during the music generation.

### C. Data Processing

The EEG data recorded by the amplifier are transported to the message window to process data and compute the corresponding musical parameters. These programs are all written with C language.

After calibrating the EEG signal into microvolt, the referred channels must be chosen. Here we take the left ear as on-line reference. In this version of system, only one channel was translated. And then, the data have to be processed in two ways, the first is that the data were down-sampled to 100Hz, and send to the next step for wave display, the second is utilized to compute the feature parameters, including the event, amplitude, and power. The definitions are as follows:

- Event: defined as two EEG waves; i.e., if a note begins when the wave cross the zero from negative to positive, it will end when the same thing presents for the third time.
- Amplitude: the mean value of amplitude of the EEG waves in an event.
- Power: the average power during the event.

In this work, we utilize a method based on waveform event for mapping. The details are shown in Fig. 2. The EEG data are analyzed to extract the event, amplitude, and power, and these are reflected by the MIDI notes' characters, the duration, pitch, and intensity (volume). The timbre of the notes is fixed with piano. The conversions are according to the scale-free power law followed by both EEG and music [6].

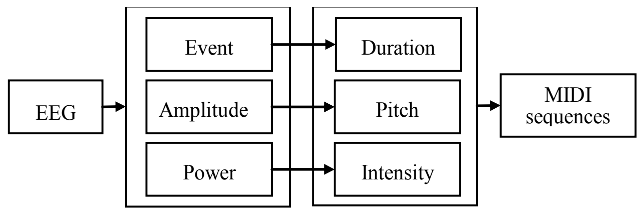


Figure 2. The mapping rules from EEG to music parameters.

### D. Music Synthesizing

After the computing of the musical parameters, the brain music would be generated by the computer. In the present work, Max/MSP, a software programming environment optimized for flexible real-time control of music system [11], is chosen for on-line brain music performance. It is currently the most popular environment for programming of real-time interactive music performance system. Max/MSP is a very mature, widely accepted and supported environment, which allows a graphic interface to develop the program, and the visual subjects in the environment are the units for programming. Therefore, it also supports arithmetic or extended functions and allows new subjects to write with C language.

In this work, the data receiving subject and the music mapping subject are both programmed with C language based on the SDK of Max/MSP, and they can receive the real EEG data from the amplifier and obtain the note's parameters, respectively. And we also design a window in Max/MSP to show the real EEG data, the musical notes which were played on a virtual piano, and the staff updated with the notes. The music synthesized can be recorded for replaying and saved as MIDI files.

## III. RESULTS

As a pilot study, we use the EEG data during eyes open and eyes closed as an example. Fig. 3 and Fig. 4 show the results. When eyes open, the amplitudes of the EEG are lower than when eyes closed, so the music during eyes open have higher pitch than the music during eyes closed.

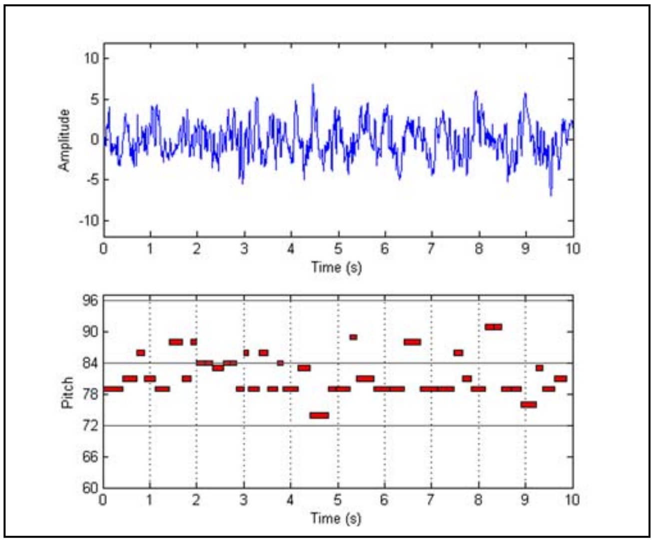


Figure 3. Brain Music from eyes open. The upper panel shows the raw EEG data, and the under pannel shows the musical notes translated by the EEG.

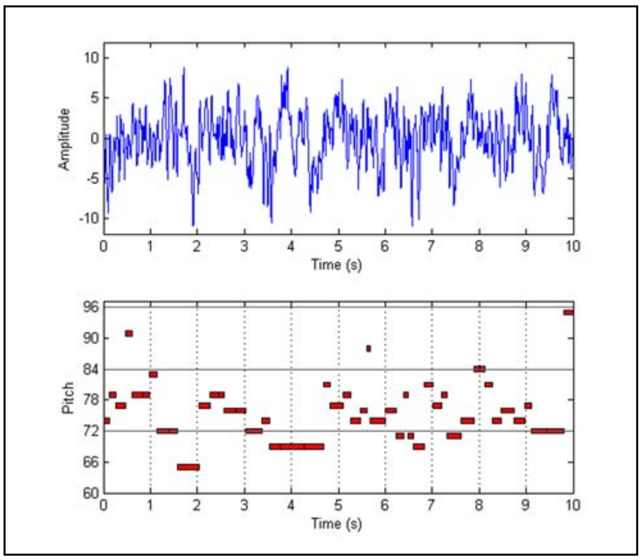


Figure 4. Brain Music from eyes closed. The upper panel shows the raw EEG data, and the under pannel shows the musical notes translated by the EEG.

## IV. DISCUSSIONS

The musical representation of human EEG is a novel attempt in brain investigation, and we believe that it can be a window for the brain functions. Whatever the methods used for music generation, the brainwave music sounds are the auditory reflection for the EEG features related to human mental states. For example, the amplitude, the most important character in temporal domain, depends on the mental activities. The sleep EEG usually has voltages approach to 150μV, while it is less that 50μV during quiet awake state [16]. Another essential character of EEG is frequency. EEG frequency range usually is divided into six bands: slow cortex potential (SCP), delta, theta, alpha, beta and gamma band, respectively. The neurophysiologic origins of oscillatory activities within these bands are not known in derail, but it is believed that the mechanisms of brain activity are related to these bands and these rhythms are from specific positions of the brain. Such information is considered in the brain music mapping rules [5, 8] and we believe that listening to these essential features can help us to perceive the brain activities. In addition, the nonlinear features are also used in EEG investigation, and some results show that the different states of EEG have different scaling properties [12]. In CBM, we have considered the power law followed by both EEG and music [6].

There are a number of advantages to perceive the brain via an auditory music. First, the human auditory system has higher resolution than visual system in temporal aspect. Second, researchers hypothesized that the inherent ability of the auditory system to process multiple auditory streams in parallel, a contrast to the human visual system's serial processing of multiple objects [13]. Finally, the human aural processing can deal with much higher complexities than those used for scientific purposes, because human have the ability to distinguish between several simultaneous voices or instruments even in a noisy environment, which provides a good reason to use music to deal with multiparametric data set, such as EEG [14]. At last, listening to music is particularly comfortable and interesting compared to staring at the screen.

The possible applications for real-time brainwave music system have great significance in medical, scientific and artistic fields. It can be used as an EEG monitor or alarm in daily monitoring and for specific neuropathy such as epilepsy [7, 13]. And the brainwave music has potential effect on music therapy. There is an attempt to use brainwave music to treat the insomnia [15], and the proposed brainwave music generation is used in rat experiment. The results show that the music from sleep EEG of rats can improve their arouse states. In sense of science and technology, the brainwave music system is an extended version of BCI, thus the interface for music can be utilized for music performance or feedback in control. It may serve as a tool for monitoring the brain and the cognitive research of music. Furthermore, the system is valuable in amusement, as everyone can compose music for oneself just by the system.

However, there are still problems in such a system. The most essential problem is how to keep balance between science and art. A direct rendering may cause a stochastic MIDI sequence, which has less music aesthetic feeling, and if more composition rules are considered, the more biological information may be lost, such as the BCMI system [9, 10] and our previous work of brainwave music generation based on wavelet analysis [8]. Moreover, the mapping from EEG to music also depends on our understanding of the brain. Thus the intrinsic scientific meaning of a mapping rule strongly depends on the development of the brain science. By the way, the effectiveness of CBM in feedback or therapy needs to be evaluated with experiments, thus a lot of works need to be done in the future.

With the development of signal processing, brain function and computer music composition, the real-time brainwave music will be more scientific and artistic. We expect that we can use the EEG for direct brain communication or online composing with further training and to understand human brain deeply.

## ACKNOWLEDGMENT

The authors thank to Jiehui Hu for English smooth and Hua Yang, Jing Lu for discussions.

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