

SONIC EXPLORATIONS WITH EARTHQUAKE DATA

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ABSTRACT

The composition “underground sounds” - an interdisciplinary project including a concert piece as its artistic element - deals with the phenomenon of the constantly moving, therefore resonating earth and is based on data taken from an earthquake which reached 7.8 on the Richter scale and triggered a tsunami on April 1st, 2007 close to the Solomon Islands in the Southwestern Pacific.

The data from several related seismic events was provided via a real-time data server belonging to the GEOFON network of seismic stations and converted to audio data using programs specifically developed for that purpose. “underground sounds” is not an audification; the seismometers records were used as raw material for several applications of signal processing effects. The four parts of the composition concentrate on different characteristics of seismic events including sounds of the same seismic event recorded by different stations, the filtered harmonic sounds of the measuring instruments and the output of the separation of the earthquake’s impulse-like components from the earth’s constant movements, each used as separate instruments in the composition.

1. INTRODUCTION

Audification of seismic data is not a new field of investigation. It has been practised and explored since the 1960’s - even though with different kinds of questions and results. Speeth (1961) as well as Frantti and Leverault (1965) worked on the distinction of “natural earthquakes” and atomic explosions. Another outstanding work is Chris Hayward’s publication “Listening to the earth sing”, presented at the ICAD (International Conference of Auditory Display) in 1992. Hayward deals with “*detailed analysis of wavelets and data from seismics where artificial quakes are used for exploration geophysics*”, quoting Florian Dombois [1]. Dombois himself shows a lot of interest in the connection of arts and science¹ [2] concerning further exploration of earthquake data, as documented in several publications.

1.1. About the project/composition

The project’s starting point can be seen as the problem of earthquake prediction. The possibility of deriving and connecting with global earthquake data and efficient networking, as well as the immense amount of available data, were the

¹“Forschung als Kunst - Kunst als Forschung”

reasons for our interest in the topic and the extension of our artistic work, which ranged from playful and spontaneous experiments in perception to the close examination of data streams in the attempt to parse complex relationships and information, rendering them transparent.

Besides dealing with the question of earthquake prediction, further intentions of the composition were to explore and examine very specific sounds and textures appearing during earthquake processes. Concentration focused mainly on the following characteristics:

1. the sound of earthquake events and the earth’s movements, filtering out as much interference as possible,
2. the earth itself as resonance corpus,
3. the measuring instrument(s) and its (their) sound’s harmonic components of its (their) sound during the recording process, and
4. influences on triggering earthquakes, in the case of this project the sun’s electromagnetic field.

Another field related to the artistic implementation is that of human perception and emotions during an earthquake. The possibility of drawing parallels between the phenomenon of an earthquake event and the development of a musical composition was examined. For this, and the need to observe several parameters during the course of an earthquake, long-term recordings were required. A direct conversion of the data, in this case audification, and a direct mapping of parameters in spatialisation was not intended.

2. THE DATA

2.1. Data formats

The seismic network GEOFON [3] is just one of several networks which provide earthquake event data in different formats. Other examples are IRIS (Incorporated Research Institutions for Seismology), BDSN (Berkeley Digital Seismic Network), NEIC (National Earthquake Information Center) and Orfeus (Observatories and Research Facilities for European Seismology). With the help of specific programs the user is able to check the availability of near-real-time data and its latency [4], derive near-real-time waveform data streams [5] and download data archives.

Earthquake event data is described as control and waveform data stored in different kinds of formats such as SEED (Standard

for the Exchange of Earthquake Data), SAC (Seismic Analysis Code) and SEG-Y (file format developed by Society of Exploration Geophysicists) has to be converted to audio data afterwards.

2.2. SEED / miniSEED format

The main reasons for using SEED [6], an international standard format for the exchange of digital seismological data, were that it is one of the newest formats, is well-supported and documented and shows a great deal of detailed information, such as glitches and sample rates.

SEED can be divided in two parts: dataless SEED volumes and data-only SEED records (miniSEED) [7]. Dataless SEED volumes contain metadata and control data that provide mainly information about the seismic stations and consist of Volume Index Control, Abbreviation Dictionary Control and Station Control headers, whereas miniSEED data records are without any of the associated control header information but contain the seismic waveform. Information about specific earthquake events and stations was preselected by the composers and therefore available for querying the appropriate waveform stored as miniSEED.

2.3. Data retrieval programs

During the course of the project several programs, either GUI-oriented or command line-based, were tested as request tools for data retrieval. SeismiQuery and jweed are some examples for GUI-oriented software, whereas jrdseed, verseed and SeedLink are command line-based. There are also programs which operate seismic waveform processing, such as SAC, interesting for analysis and filtering of seismic signals.¹

The decision to use the miniSEED format and slinktool (a SeedLink protocol client) for the project was made because slinktool is a non-GUI command line tool. The user is able to derive waveform data streams of a station for a user-defined period of time.

Although the request tools jweed and SeismiQuery are easy to use and store data in the SAC and miniSEED formats as well, they do not provide continuous data streams, as they only hold a small time span of the tremor. The programs jrdseed and verseed also produce SEED and SAC but not miniSEED files. Furthermore the user must be aware of the fact that identically named formats are not always organized in the same way when coming from different networks.

2.4. SeedLink, slinktool

SeedLink is a data transmission protocol intended for use on the Internet or private circuits that support TCP/IP. Requested data streams may be limited to specific stations, locations and/or channels. All data packets are 512-byte Mini-SEED records. The most common implementation is the SeedLink [5] server within the SeisComp (Seismological Communication Processor) package developed by GEOFON.

slinktool, used in version 3.8 for the project, is a command line SeedLink protocol client and part of SeisComp package as well.

Example of a command line:

```
slinktool [options] [host][:][port]

./slinktool -s 'BHZ.D' -S 'GE_APE'
-tw 2008,01,16,00,00,00:2008,01,16,00,01,00
-o data.mseed -nt 10 -p -u -vv geofon.gfz-potsdam.de:18000
```

Options:

- s 'BHZ.D' : type of seismic data, specifying certain physical configuration (see 3.2: The seismometer's channels)
- S 'GE_APE' : name of station in: Network_Name form
- tw yyyy,mm,dd,hh,mm,ss: yyyy,mm,dd,hh,mm,ss : time span: year, month, day, hour, min, sec. (of beginning): year, month, day, hour, min, sec. (of end)
- o data.mseed : miniSEED output files (in ASCII)
- nt timeout : network timeout (in sec.) for trying to establish a new connection to the network's data server when there is no data delivered in timeout seconds, default 600
- p : details of currently downloaded miniSEED data, including information of header and 100/1000/1001 blockettes
- u : number of data samples in data package
- P: to check if station is active and delivers data

The number of samples from data blockettes, though equal in time span, can vary due to data gaps caused by timing [8], recording and transmission errors [9].

2.5. Conversion to audio data

The conversion of miniSEED to audio data works with three libraries: SeisFile [10] (library for reading various seismic file types), SeedCodec [11] (collection of compression and decompression routines for standard seismic data formats) and jMusic [12] (for conversion of seismic waveform to acoustic waveform data). Data from different stations can be compressed using different algorithms and must be first decompressed and later audified. One of the most common compression methods is the Steim1 compression [13].

A miniSEED2aiff.java program was developed to open and validate the file, extract parameters and apply an algorithm for the decompression, normalisation and writing of the waveform data as an audio file.

3. SEISMIC NETWORKS AND CHANNELS

3.1. Seismic networks

The seismic data used for the project was derived from nine stations [14] of the Geofon Network data center provider around the world. Different channels corresponding to different measuring instruments with various sampling rates and directions of the earth movement were chosen. All stations have distinct characteristics according to their position on earth.

3.2. The seismometer's channels

The SEED format uses three letters to name seismic channels. The first letter specifies the sampling rate in which the seismic data is recorded, the second describes the family to which the sensor belongs and the third letter specifies the physical configuration

¹Links to all the cited programs can be found on <http://www.iris.edu/manuals/>.

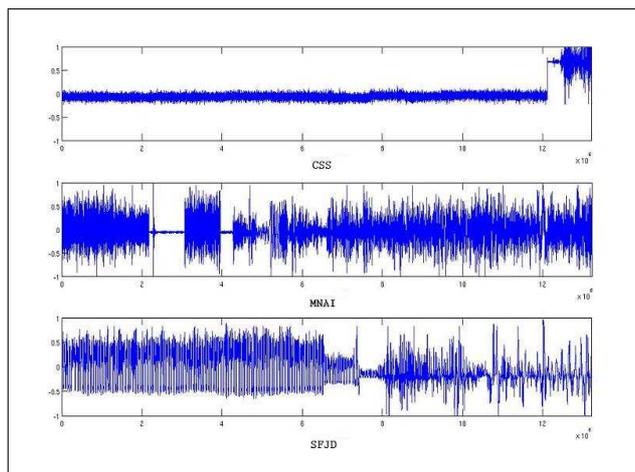


Figure 1: Detail of audio tracks from the stations CSS, MNAI and SFJD

of the members of a multiple axis instrument package or other parameters as specified for each instrument [15]. Each station provides several types and a differing number of channels.

The measuring instruments produce high frequency harmonic components according to their eigenfrequency.

Code	Location	Latitude	Longitude	Altitude	Streams
APE	Apirathos, Naxos, Greece	37.0689	25.5306	620.0	HH/SH/BH/LH/VH
CSS	Mathiatis, Cyprus	34.9611	33.3310	396.0	HH/BH/LH/VH HH/BH/LH/VH
EIL	Eilat, Israel	29.6699	34.9512	210.0	HH/SH/BH/LH/VH HH/SH/BH/LH/VH
GSI	Gunungsitoli, Nias, Indonesia	1.3039	97.5755	107.0	HH/SH/BH/LH/VH HL/BL/LL
ISP	Isparta, Turkey	37.8433	30.5093	1100.0	BH/LH/VH BH/LH/VH
MNAI	Manna, Sumatra, Indonesia	-4.450	102.917	0.0	HH/SH/BH/LH/VH HL/BL/LL
PUL	Pulkovo, Russia	59.767	30.317	65.0	HH/BH/LH/VH HH/BH/LH/VH
SFJD	Sondre Stromfjord, Greenland	66.9960	-50.6215	80.0	00.BH/LH/VH 10_HN/LN
SNAA	Sanac, Antarctica	-71.6707	-2.8379	846.0	HH/BH/LH/VH HH/BH/LH/VH BH/LH/VH

Table 1: Location and available streams of the nine stations used [3]

4. ALTERATION OF AUDIO WAVEFORMS

Playing the audio data at different speeds allows one to listen to different kinds of sounds and concentrate on distinct phenomena. High- and low-pass filters as well as bandpass filters were used.

4.1. Source filter separation with use of cepstrum

The earth's resonance in cepstral domain is of slow and the tremor signal of fast variation. Therefore the signal recorded by the measuring device corresponds to the output signal (time domain), the source signal to the tremor signal and the impulse response to the earth's resonance between hypocenter and recording station. In the cepstrum (source filter separation) [16] equation, the

earth's resonance is assumed to be linear and time invariant. G. P. Angelieri's article "A statistical approach to the extraction of the seismic propagating wavelet" [17] gives further insight on the topic: a model of the seismic trace is designed as convolution between the propagating wavelet (source) and the reflectivity series of the earth (filter) with white noise added to the trace.

With the help of a Matlab program computing the source-filter separation model, the fast, impulsive part (excitation) of an earthquake is separated from the earth's constant movements. This enables the artistic use of the two separated parts described above as independent "instruments".

5. THE COMPOSITION

"underground sounds"-
sonic explorations with earthquake data
(electroacoustic composition in four parts)

- 1_tremor
- 2_trigger
- 3_wake
- 4_vacillation_1_2_3

The four parts of the composition display specific structures of earthquakes.

Earthquake sounds typically oscillate between two poles: the normal sounds of the earth's resonance and the sounds of the earth excited by an earthquake's tremor. The undulatory sound of the normally resonating earth, varying slightly, contains noise as well as harmonic components. Although the overall impression of the sound is unitary, it shows clearly distinguishable differing densities and volumes in particular frequency ranges of its rich spectra, influenced by the choice of specific sampling rates. The use of different sampling rates also enables both differing gradations of sound color and the highlighting of unique textures which proceed without end and without any sign of a regular or predictable pattern.

In contrast, the brief, impulse-like tremor appears unexpectedly, its sudden intensity drawing attention to itself. It is of high amplitude and even broader frequency range than the resonating earth.

When composing "underground sounds" and "1_tremor" in particular, one of the concepts pursued was the exploration of our own perception. In this case we chose extracts from earthquake recordings to work out specific questions (see itemization section 2). The extracts became musical motives, which were combined to construct musical patterns. The variations were executed using several signal-processing effects. However, the focus lay on creating manipulated versions of, and patterns within, a continuing overall sound.

Spatialisation was used as a function for displaying the artistic implementation of the field of human perception during an earthquake event. The first performance took place in the Institute of Electronic Music and Acoustics' (IEM) concert room Cube [18], equipped with a hemisphere consisting of 24 loudspeakers and allowed reproduction of three-dimensional soundfields following ambisonic principles [19].

5.1. 1_tremor

The earthquake's development is examined and recreated artistically, using material from various stations. Signal alterations of the audio data include various playback speeds and the same channel type from different stations. In terms of spatialisation, the sound in the first part of underground sounds comes from above and behind from the audiences perspective, underlining the unpredictability and indirectness of the process.

5.2. 2_trigger

The envelope of a specific earthquake's audio file is decisive for the form of the second part of the composition, triggering time windows where another layer of sound can be heard. The envelope itself is very unique, so even if the second layer of sound is of either harmonic or noisy nature, its structure is still associated with earthquakes.

The second layer of sound consists of the filtered harmonics of the measuring instruments, generated by the excitation of each seismometer's eigenfrequency through the same frequency of seismic ground movement while recording. Switching over to another measuring sample rate does not affect the resonating frequency corresponding in our case to a specific pitch.

In thinking about the earth as a resonance corpus, the question arose of how an extraterrestrial tremor would sound. Examples of scientific exploration in this field are mentioned in Till F. Sonnemann's thesis [20], where he evaluates data of lunar seismic events. Bearing in mind that the sun's electromagnetic field exerts a great influence on the earth's magnetic field, which in turn affects seismic activity, audio files of the solar electromagnetic field [21] were used and source filter separations applied as before with data from the earth. The sun's constant movements were reconnected through convolution with the impulse-like part of an earth's tremor. From an artistic point of view this could be interpreted as reexciting the sun's electromagnetic field with the earthquake's impulse.

The sound distribution is almost identical to that in "1_tremor", the sources still positioned mainly in the back. Now, however, single sources also come from the front. The Cube's ambisonic sound system allows sound to emerge at almost ground level, so that the audience is surrounded and covered by sound. Only the front-center and front-left areas of the hemisphere remain silent.

5.3. 3_wake

The idea of placing different source signal separated audio files in linear succession through convolution arose. This describes a concentrated audio file combining several earthly resonances with the result of a "hyper-earth". Random playback speeds are also utilized. Through multiplying the spectra of selected audio files a new waveform is created. This waveform, to the ear of the listener, sounds even richer in the density of contained events.

The change in sound distribution from the second to the third part of the composition displays a noticeable switch from ground level to the ceiling. The distancing of the sound from the audience corresponds to the distancing of a person from past events.

5.4. 4_vacillation_1_2_3

In three parts differing sounds of the earthquake's aftershock are presented. Besides source signal separation, different playback speeds were used.

4_vacillation closes the parenthesis opened with "1_tremor" at the beginning of "underground sounds". It reopens the possibility of an unpredictable event, building and releasing musical and psychological tension in a quick, dense succession without any preparation.

6. CONCLUSIONS

The preoccupation with the topic of earthquake sounds led to the present composition and project description.

Considering the fact that the earth is constantly moving, the scientific (but not artistic) use of certain tools can be questioned for example the source filter separation: the earth's movements are assumed linear and the general differentiation between the earth's "normal" movement and an earthquake's process from beginning to end cannot really be drawn.

Difficulties concerning audifying earthquake data arose in deriving data blockettes of the same length.

Changes of sample rates in the measuring instruments themselves complicate the conversion of audio files. Cooperation with seismologists would provide insight on earthquake technical topics as well as enrich the artistic side of the project and allow the artists to go into greater detail.

From an artistic point of view the whole project, with the composition as end result, was influenced by both technical and artistic elements. Sound was always a primary consideration. The artistic adaptation of the source materials is of course done with a wink and a nod, so to speak: the usage of source filter separation and the "sound" of the sun's magnetic field, for example, must not be interpreted as serious in scientific terms.

Both the further exploration of earthquake sounds and the connection of different kinds of data for a single event would be of great interest. One example might be the connection of data of the earth's electromagnetic field with earthquake data, though it is questionable whether such a huge amount of data would improve or deepen earthquake prediction or other fields of scientific research. When linking different types of data consideration must also be given to the technical conditions and possibilities, as well as the availability of appropriate material.

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