Seismic Data Analysis Using Digital Music Technology - Applications in Hydrocarbon Exploration

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3 authors:

Paolo Dell'Aversana
Eni SpA - San Donato Milanese (MI)

Gianluca Gabbriellini
Eni

Alfonso Amendola
Eni Next LLC

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Seismic Data Analysis Using Digital Music Technology - Applications in Hydrocarbon Exploration

P. Dell'Aversana* (Eni S.p.A. E&P), G. Gabbriellini (Eni S.p.A. E&P) & A. Amendola (Eni S.p.A. E&P)

SUMMARY

We introduce a novel approach for geophysical data processing, interpretation and integration. It is based on ideas and methods imported into the geosciences from the domain of sound analysis and digital music production. The presentation is divided in two main parts. First we introduce the theoretical and technical background. Starting from the already known concept of 'sonification' we derive other inedited ideas and methods. We explain how these are complementary and not substitutive of the methods currently used for geophysical data processing, imaging, and interpretation. In the second part, real applications of integrated imaging and sounding analysis addressed to hydrocarbon exploration are discussed.

Introduction

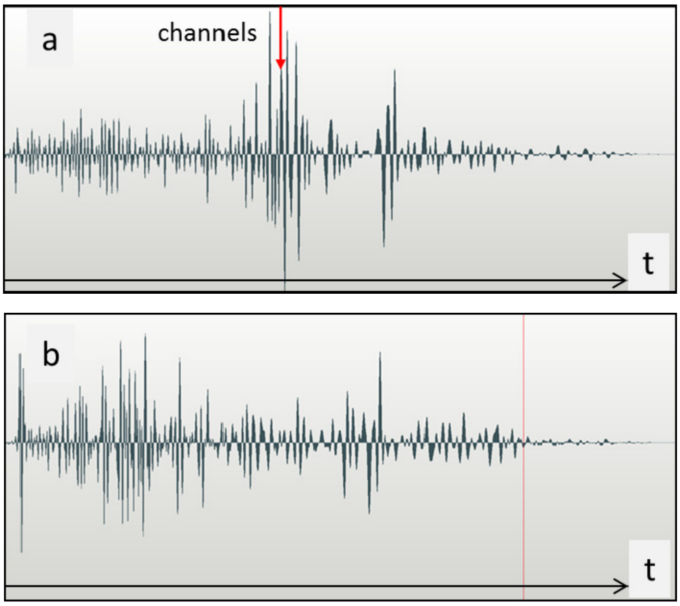
Data 'sonification' represents a relatively young field of study including key aspects of physics, cognitive sciences, communication engineering, psychology, digital music. It has useful applications in data management, sociology, economy and many other fields of study. One of the goals of data sonification is to use sounds to improve the process of extraction of information and acquisition of knowledge (Worrall, 2000 and 2009). A similar approach can be used also in the domain of the Earth disciplines. For instance, transforming geophysical signals into sounds (Hayward, 1994, Kilb et al, 2012) can produce practical benefits on data analysis and interpretation in exploration geophysics. Analysing the pitch and volume variations simultaneously with visual frequency and amplitude changes increases significantly the amount of information perceived at the same time. The key idea is to combine the advanced technology available in the domain of electronic and digital music, with the latest developments in the field of cognitive sciences, for improving geophysical data analysis (Dell'Aversana, 2013). A lot of tools and formats normally used in electronic music (such as *wav*, *mp3*, *MIDI*) can be "exported" and applied into the domain of the geosciences. Musical software tools and protocols allow easy sound manipulation, analysis, and integration. In particular MIDI protocol is addressed to link heterogeneous information through multiple types of media. Moreover effective pattern recognition tools aimed at detecting structured sounds in a noisy background, can be applied in geosciences for automatic recognition of geophysical anomalies of interest. Of course the low frequency band typical of many geophysical signals must be translated into the audio frequency band (20-20000Hz) before being listened in terms of musical patterns. This can be done easily using functions of 'pitch switch" or equivalent editing tools commonly available in the software packages used in digital music. In this work we highlight the potential applications in different fields of the geosciences. In particular we discuss interesting results recently obtained by us applying the sonification approach for seismic data analysis addressed to hydrocarbon exploration.

Theoretical background

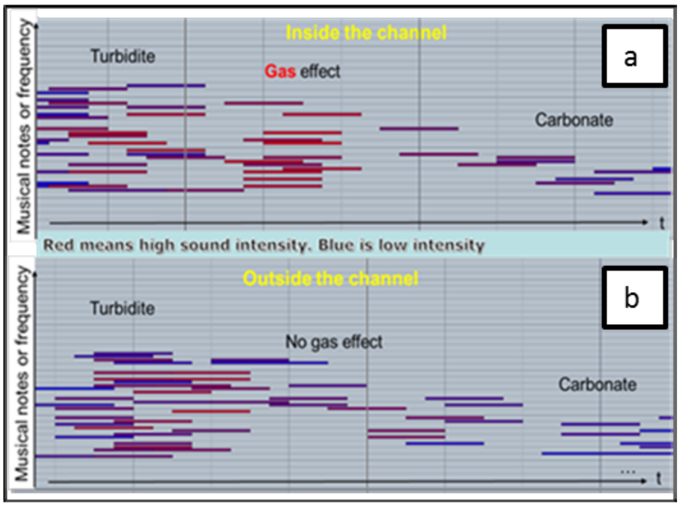
Geophysical signals are commonly represented in terms of spatial distributions or time series of physical events. These are characterised by a certain frequency spectrum. A musical piece can be considered in a similar way: it is a sequence of musical events with a certain frequency spectrum. Based on this concept we can transform a geophysical signal into a sound file. For instance the FFT of sequential segments of a seismic trace can provide with the correspondent sequence of frequency spectra (spectrogram). These can be transformed into musical messages (sound pitch, intensity, length and so on) that allow creating a MIDI file (MIDI stays for 'Musical Instrument Digital Interface'). After that transformation, we can upload the file into a software platform used for analysis and/or production of digital music; finally, we can process, interpret and combine geophysical signals in terms of sounds and images at the same time. The above steps allow creating a correspondence between geophysical signals and digital sounds. These can be recorded in different types of files and formats. After transforming geophysical signals into sounds they can be listened, processed, combined, interpreted using many types of musical and sound software tools, such as a sequencer. Sequencing software (or simply sequencer) allows recorded MIDI files to be manipulated and combined with "audio traces" (such as wav and mp3) using standard computer. A sequencer allows each channel to play a different sound using internal synthesisers. Thus, many geophysical signals can be transformed into sound traces, combined and played simultaneously. Modern sequencers can deal with an unlimited number of traces. This approach can be applied also for combining geophysical responses of different nature (seismic, gravity, EM, composite logs, etc).

Applications to hydrocarbon exploration

The approach based on converting the geophysical response into associated sounds and images can be extremely useful in hydrocarbon exploration. In general geophysicists look for anomalies emerging from a background, like geophysical responses associated with oil/gas presence, specific geological structures or lithologies, faults and so on. These anomalous geological "objects" produce a seismic (but also electromagnetic, gravity, magnetic and so on) response that is generally characterised by a frequency spectrum significantly different from the background. Consequently, transforming the frequency spectrum into sounds can help to detect and/or highlight meaningful geophysical anomalies. One advantage of this approach is that we can perceive all at once the whole frequency content in terms of a complex sound. Instead, every imaging technique is necessarily limited in terms of simultaneous visual representation of different frequency components. For instance, figure 1_a and 1_b show respectively a seismic trace crossing a channel filled by gas and outside it. We converted these traces into correspondent MIDI files (figure 2_a and 2_b, respectively) and represented the result in a so called "virtual keyboard". Here the vertical axis represents increasing frequency or increasing tone of musical notes (pitch). The horizontal axis is the "time of MIDI execution" that is proportional to the seismic travel times in the seismic traces. Colours indicate sound intensity (red is high, blue is low).



Figures 1_a *(top) and* ***1_b*** *(bottom). Seismic traces inside and outside the channels, respectively. (Channels position is roughly indicated by the arrow).*



Figures 2_a *(top) and* ***2_b*** *(bottom). Simplified (low pass filtered) MIDI files derived from the traces inside and outside the channel, respectively.*

The MIDI files of figures 2_a and 2_b are simplified (low pass filtered) musical representations of the correspondent seismic traces (MIDI translation cannot preserve the whole original information; however the most recent algorithms for converting wav files to MIDI files are very accurate). The key message is that the main seismic features, like the events associated to turbidite, gas filled channels

and carbonate, appear very well in the MIDI file. They are clearly recognizable in terms of their frequency spectrum. All these features (channels, carbonates and so on) can be analysed, processed, played, combined using all the tools commonly used in the domain of digital music. For instance when the MIDI file of figure 2_a is played with a 'classic piano', the music is significantly different from the MIDI of figure 2_b. The most relevant 'musical' difference is caused by the presence of a channel filled by gas in the first case and water bearing in the second. This 'musical' interpretation is supported and calibrated by well log information. The presence of gas effectively seems to be responsible of the typical MIDI effect highlighted in the figure 2_a, and not visible in figure 2_b. We searched for the same effect also on many other traces converted into MIDI and played with different digital instruments. The percentage of repeatability of this effect was 100%.
In a more general sense, with this approach we have the opportunity to listen to the entire frequency spectrum associated with geophysical signals. This suggests that the sound associated with seismic signals can be collected into a data base to be used by tools of musical pattern recognition. For instance Figure 3 shows the musical notes extracted from the MIDI file associated with the gas filled channels, approximately in the crossing point between the vertical bar and the dashed line. This time no low pass filter was applied. The notes with high pitch (very clear in the figure) in this case are caused mainly by the high frequency content of the spectrum associated with the structural complexity of the channels. The correspondent MIDI music can be listened using a sequencer and selecting different digital instruments. Using a sequencer scanning the MIDI file through the channels, it is possible to appreciate how the music changes depending on the frequency spectrum. In this way an interpreter can look at the seismic section and, at the same time, can appreciate the musical patterns associated to variations in terms of the frequency content. A musical dimension is added to the visual analysis. We have directly verified, doing a lot of tests on real data, that this approach based on simultaneous imaging and sounding attributes improves the interpretation itself and the sensitivity of the interpreter in capturing interesting anomalies, detecting faults, distinguishing different geological structures, recognizing hydrocarbon bearing channels, and so on.

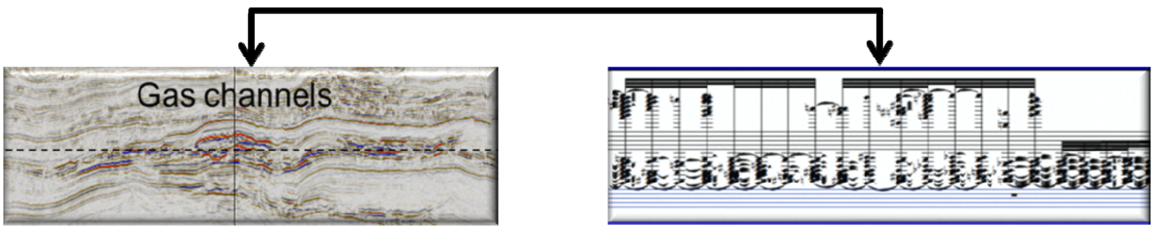


Figure 3 *Translation of seismic data into a MIDI Musical sheet for a portion of a gas bearing channel.*

A test of musical pattern recognition applied to seismic data

In order to support the ideas discussed in the previous paragraphs, we tested on real data the possibility of automatic detection of geological structures of interest in hydrocarbon exploration using an algorithm of musical pattern recognition (Wang et al., 2003). For the scope we selected a seismic volume calibrated by well logs, in correspondence of a recent important gas discovery of **eni** E&P. First we transformed the seismic traces into musical files in different formats (wav, mp3 and MIDI). Then we created a data base including musical files corresponding to seismic traces in correspondence of important geological objects, like sand prone channels filled by gas. Finally we used an approach of "audio fingerprinting" for attempting an automatic pattern recognition of the gas channels in the experimental data volume. The final results are very encouraging. In fact the algorithm is able to classify correctly almost 100% of the seismic/musical information. For instance it is able to perform a very good distinction between traces inside and outside the gas channels. The good news is that the musical recognition works properly also after transforming the seismic data into MIDI format. It means that segy-to-MIDI translation preserves the most relevant information associated with geological features of interest. This preliminary result encourages us to use a musical fingerprint approach for supporting geophysical data interpretation.

Final remarks and possible developments

The attitude of human brain for sound perception, recognition, analysis, and interpretation, together with effective tools of audio-fingerprinting, can be used in geophysics. This means that the visual analysis of geophysical signals can be supported (not replaced) by sound analysis. This bridge between geosciences and music is built by transforming geophysical signals into audio files, MIDI files, musical sheets, and analysing/playing them using software tools like sequencers and virtual synthesizers. Many other types of applications, not restricted to the seismic domain, are possible. These are, for instance: sound analysis of composite logs, geological formation evaluation by sound pattern recognition, sound characterization of hydrocarbon reservoir, spectral decomposition of geophysical signals, multiple removal using sound de-reverberation techniques, and so on.

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