SONIFICATION OF OIL AND GAS WIRELINE WELL LOGS

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ABSTRACT

Wireline logs are the most common instrument that geologists and geoscientist have in order to know the downhole formation nature and conditions. They are created by large data sets that are acquired down the hole in the field. The fact that they are plotted in long (sometimes hundreds of meters) charts with several curves at a time turns them useless for those who are visually impaired. Turning the values of each one of the curves into different sounds, or different harmonic notes is a way to improve the user experience for regular users [1] , and a way to make blind scientist keep on studying downhole formations behavior. This work presents a software development that turns those logs into sound so as to allow logs be playbacked instead of viewed.

1. INTRODUCTION

As a result of have been working with Wireline logs for so long, facing the daily challenge to effectively navigate and analyze large data sets [2] , and knowing that there are many users that could really make a profit of sonificating them, I began the develop of the system in 2011.

The idea of starting the project came up to me as a result of having a blind member of my family (my father's brother) and a diabetic daughter (she is nowadays sixteen and was discovered diabetes the week before she became six).

My uncle was losing his sight since he was young, until a moment he was declared legally blind. Having this time he was able to learn many things in order to allow him keep on working and moving around the city [3]. He told me that sounds, smells and heat-sources help him day by day to perform his tasks.

Diabetes is an illness that, if it is rightly controlled since its discovery, the impact on the overall health can be attenuated, but, if the controls are not performed in the right way, health is seriously affected, and the first organs implicated in its effects are those with tiny capillaries, like kidney, and eyes, in this case causing even blindness [4].

In spite of the fact that I'm a full-time worker, during some free time I was able to find, I tried to make it work, and, counting with the honor of being helped by two blind geoscientists, one blind non-professional tester and the whole crew of Wireline engineers belonging to the Schlumberger Neuquen Base and some members of Data & Consulting Services from Buenos Aires, we performed the usability tests in 2012, improving many aspects of the user experience, sending samples and receiving the feedback, testing and installing the software in two different Operative Systems, letting the software be ready this year.

The aim of this paper is to show what was done besides sonification in our industry, (knowing that there is much more to do), the process we have followed in order to make the system work, and the future application possibilities that this technique has in order to help other coworkers perform their tasks.

2. WIRELINE LOGS

Wireline logs are largely used in the oil and gas industry, they are basically charts in which the values of several sub-surface formation characteristics are plotted indexed by depth [5]. These values help geoscientist to determine many things about the formations; in particular, the use of logs within our industry gives clues to help find the oil and gas migration paths and reservoirs [6].

There are several types of standard logs [7] in which the combination of variables plotted are really wide, and also some of those logs not only have curves, but also images of the wellbore, sonic waves and magnetic resonance decay time spectrum.

Most of the wireline logs are depth-indexed, showing several curves behavior at a time within a depth interval, but there are also some logs that are time-indexed, like those related to formation pressure or production logging [7].

First produced logs were hand-plotted while data was acquired [8], today, field engineers are used to use computer-generated logs as continuos paper hard prints, sometimes hundred-meters long in different scales, like 1:200 or 1:40 for more detailed characteristics; but the use of Acrobat pdf files is being the prefered source when interpretating data sets remotelly.

Datasets that provide the source of data values for the charts, and that are the files in which the acquired data is stored, are digital files with the file extension .DLIS (Digital Log Interchange Standard) defined by the Recommended Practice 66 [9] of the American Petroleum Institute. These DLIS files are complex structures but, using different software packages, certain frames of values can be extracted from them in order to prepare plain-text files showing tabulated data, with the .LAS

file extension using the guidelines defined by the Log ASCII Standard of the Canadian Well Logging Society [10].
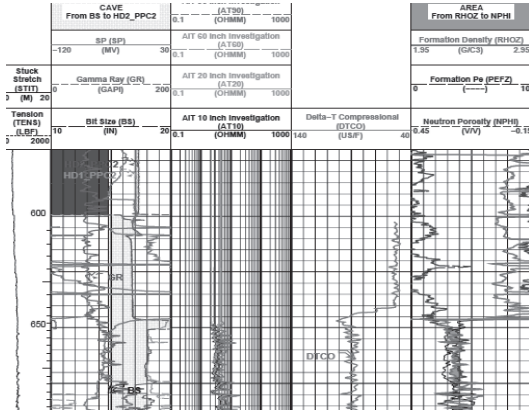

Figure 1 : standard composite log with spontaneous potential, gamma ray count, diameter of the well, resistivities in different formation horizontal depths, sonic slowness, porosities and photoelectric factor

3. WHY SONIFICATE WIRELINE LOGS

The use of sound to carry information about Wireline logs can be straightly understood in order to be applied for helping visually impaired users, but its use in the regular world of sighted field engineers is something that deserves an special paragraph specially because eyes tends to scan charts at its own speed [11], but sound is heard as it is revealed, so when performing field operations this could lead to improve the tasks being done, saving time and money in an industry in which both variables are critical.

The benefits that sonification can give were well described by Hermann T. [12] when stating that auditory displays can be used as user eyes-free, drawing attention to a process when required, giving high temporal resolution and short detection times, giving also the possibility to listen in parallel two data sets, to habituate to certain patterns, to use the auditory memory for retrieving familiar sounds for comparisons and many others without interfering with visualization.

These benefits could be obtained implementing sonification techniques to the logs, continuing with the job started by Stephen Barras, Bjorn Zehner [13], and by Robert Stewart and Samantha Brough [14], in particular to one of the most useful scopes in which the use of the sonification of graphs [15] in a real time operation could help, that is the characterization of a sub-surface formation.

Scope #1 : Formation identification

The "fingerprint" of a formation [16] can be thought as the pattern of one or more variables behavior in certain depth interval, so, the same formation will have the same variables-

pattern no matter the geographical location inside the basin nor the depth under the surface the formation lies in a specific province or county. These formation fingerprints are used to univocally identify them at all the stages of a job, and, having a sonification file of each one of the formations patterns, we could create a library of sonified formation-patterns.

Scope #2 : Logging While Drilling (LWD)

LWD is a technique used by Drilling Companies that allows the acquisition of the many of variables detailed in previous heading [17], but at the same time the hole is being drilled. LWD Engineer's control rooms are plenty of screens showing multiple charts, variables, and gauges. The drillings are aimed to target specific formations in order to allow or maximize the recovery of the oil or gas, and, experimented field engineers have to know the formation fingerprint.
Playing sonically the components of the variables that are being measured will let the operator realize which formation is drilling through at any time, based on the library of sonified formation patterns, no matter what operation he is performing at this time, and no matter if he is able or not to see the screens [18].

Scope #3 : Wireline engineer depth control

An oil or gas well could reach easily five or more kilometers depth and sometimes reservoir thickness in a place could be as small as ten meters, so, precision is critical, and assuring a correct depth control even though the cable stretch (some meters) is a key task when logging.
As mentioned by E.Childs [19], time domain behaviors are more easily perceived auditorally, so, the use of previous logs of the well in order to play the variables sounds, at the same pace the operator is acquiring the data will allow the operator to realize more quickly if the variations of the sounds being heard are similar to those being acquired, or, when a dissonance is heard, he would be able to realize if a cable stretch due to tool-stuck or upward flow is affecting the measurements as an early alarm prior to any cable-tension fluctuation detection.

Scope #4 : Mobile phone transmission of a variable being acquired.

It's a common situation that operators receive cell-phone help during their jobs in the field-site given by more experimented desk engineers. Letting the desk engineer to hear the behavior of the variable will let him know in a better way what is happening with the tools and/or formation in the remote location, allowing him to help the operator with more precision.

Scope #5 : Log interpretation while performing other tasks [18]

Fixing electronics of the tools, supporting field printers operation, driving, giving instructions to the crew are some of many tasks that operators have to perform without being able to look at the logs, they have to be looking to other places, but, playing the variables sounds will let them keep on following their behaviors even though they were not able to see them at this moment.

Scope #6: Clarification of abstract chart information

There are some special kinds of graphics like those related to Shear or Compressional Sonic services, Magnetic Resonance, or Cement Bond Log that are plotted with spectra of waves in different ways. Geoscientists have learned how to interpret these spectra, but, transforming them into sound [20] [12] lets anyone without technical knowledge to "interpret" the sound being plotted as "Good or bad Cement Bond", long or short time decay, and log or short transit time. In the experiments we have done was really useful the analogy like when hitting a free pipe with a hammer, or when hitting the same pipe but with absorption of part of the energy.

There could be many other scopes in which sonification could improve the tasks being done within Wireline; they have to be identified in order to start working on them. Oil and Gas industry leads in many aspects the use of new technologies and techniques that later are applied in many other industries, so stimulating the support of these studies could help sonification became more used.

4. SOUND MAPPING GEOPHYSICAL VARIABLES

Borehole formation variables behavior and patterns have to be converted from depth-indexed variables into time-index ones as per allow be playbacked as auditory plots by using a time scale to represent the depth-scale. As said by Ness et al [21] by using the natural ability of humans to hear periodic structure in audio signals, we can easily decode much more information of these data sets rather than just visually plotting them.
Variables being measured in Wireline or LWD have a wide range of values, but as we have a narrow range of frequencies and loudness levels that can be easily perceived and distinguished one from the others, and, in order to let each one of the variables has its specific pattern to be recognized; I've decided to base the development using MIDI standard and tools. [22] [23] [24] Each MIDI instrument, defined in the standard, has its own timbre, and also, there are many software tools that can be used for coding based on it, so the choice gave me more freedom for coding and testing.

As regards of the limited dimensionality and perception resolution [12] involved in the mapping process, the available range of notes in MIDI starts with an A0 of around 27.5 Hz, but, thanks to the advice of the testers that the use of notes under 65 Hz and higher than 5000 Hz did not allow a proper recognition of the values conveyed, the plotting range of MIDI notes was defined for our project starting with C2 at 65.4 Hz, up to D#8 with 4978 Hz. This definition gave us 76 notes [23] to cover the variations of any variable, and, in comparison with the standard resolution of Wireline printers (300 dpi) in 3¾ inch tracks (regular tracks), the relationship between sonic and paper resolution on printed logs was calculated as (Sr=76 notes, Pr=300 dpi, Tw=0.75 inch)

Sonic Resolution in notes per printed-dot:

$$R = Sr/(Pr.Tw)$$

0.34 notes per paper dot (3 dots per note), which is wide enough to reproduce with great fidelity the variations of all of our datasets variances [22].

	C	C#	D	D#	E	F	F#	G	G#	A	A#	B
Octave 0												
Octave 1												
Octave 2	X	X	X	X	X	X	X	X	X	X	X	X
Octave 3	X	X	X	X	X	X	X	X	X	X	X	X
Octave 4	X	X	X	X	X	X	X	X	X	X	X	X
Octave 5	X	X	X	X	X	X	X	X	X	X	X	X
Octave 6	X	X	X	X	X	X	X	X	X	X	X	X
Octave 7	X	X	X	X	X	X	X	X	X	X	X	X
Octave 8	X	X	X	X								
Octave 9												

Figure 2 : Notes used for mapping

For sonically identify a variable, and in order to replicate what colors, pen-tips and line widths are for visual charts, the use of each one of the MIDI instrument defined in the standard, and its own pitch, attack time, timbre and loudness envelope, make for the audition the same identification effect replicating visual characteristics of standard logs. The "*redness*" or "*blueness*" [25] of the line used for visually plot a variable, its width , and also its "*solid_lineness*" or its "*dash_lineness*" is something that can be translated by letting the user use for the same purpose, sonic characteristics of specific musical instrument, furthermore, there are some instruments that can produce continuous streams of sounds like the flute and the violin, and other instruments that produce non-continuous streams like the guitar and the drums, the choices can help the user to sonically identify each variable within a group of variables being played at a time.

The use of linear dependences between a variable behavior and its plot in a chart is the most common dependence used in our logs [5] [7], but, there are also some variables that because of their variations and the use we give to them, is better to plot using a logarithmic scale, in the example of figure 3, same interval shows resistivities in both scale systems. This led us to pre-select some variables in which their values are going to be sonified in a logarithmic scale instead of a linear one. The related variables are those that are already plotted using logarithmic scales in our visual logs and include Formation Resistivities, Water Resistivities, Thorium / Potassium and Thorium / Uranium ratios and Permeabilities.
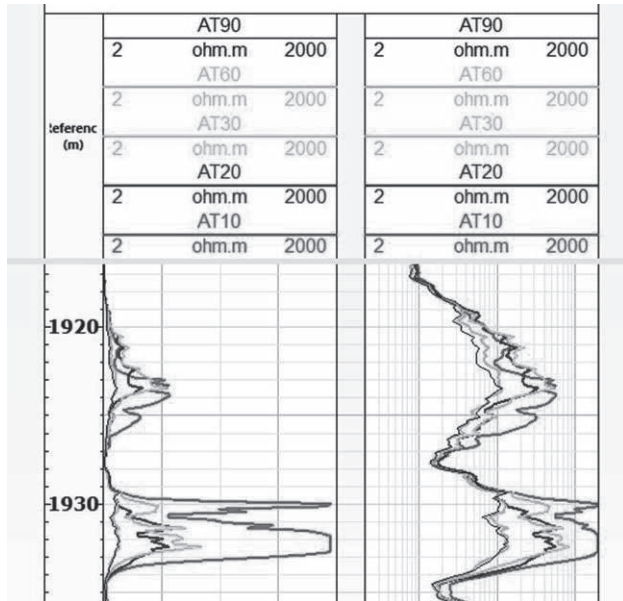
	AT90				AT90		
2	ohm.m	2000		2	ohm.m	2000	
	AT60				AT60		
2	ohm.m	2000		2	ohm.m	2000	
	AT30				AT30		
2	ohm.m	2000		2	ohm.m	2000	
	AT20				AT20		
2	ohm.m	2000		2	ohm.m	2000	
	AT10				AT10		
2	ohm.m	2000		2	ohm.m	2000	
2	ohm.m	2000		2	ohm.m	2000	

Figure 3 : Linear versus Logarithmic scales [21]

So notes being played are calculated from the interpolation of the variable value within its scale, and the 76 available notes, from the note 0 (C2 – 65.4 Hz) and the note 75 (D#8 – 4978 Hz)

$$y = 61.734e^{0.0578x}$$
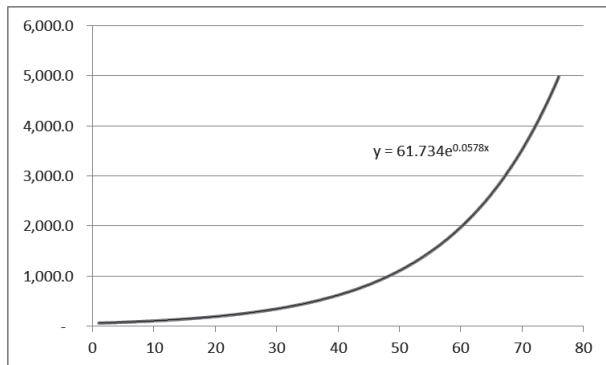
Figure 4 : Frequency (Hz) vs. note number

At first sight, the exponential relationship between the frequencies determined by the number of the linearly interpolated note seems to produce a wrong impression to the auditory user; but, as human perception for frequency and loudness show logarithmic responses [21], the final relationship between plotted values variance, and user perception is in fact linear.

This mapping method determine a positive polarity, it means, the higher the value, the higher the pitch of the sound. The reason for this is to try to match most of the polarity of the visual scales we use in our plots, and, even though there are some polarities that are usually visually plotted as negative (like in some porosity plots), the use of a unique polarity helps on not to create confusion about the direction of a trends, no matter which variables are being plotted and compared.

The use of horizontal grids [12] (as a help for visually plotted charts) is replicated in the program by the use of a main strong drum that beats with a chosen step (each meter, two meters, etc.) and three weak drum beats between strong beats, in order to allow the user divide the perception timing into four stages, as quarters of the main beating "grid".
This helps the user to determine with more precision the depth being heard.
Another guide for the user is the fact that a voice can "say" the depth value with a customizable frequency, letting the user assures he knows the depth which is being playbacked.

5. CHOSING THE MODULATION METHOD

Sonically, in the program there were two ways to modulate the values, well described by Ferguson and Cabrera [20], the finally chosen one was the to modulate the frequency of the sound being emitted, it means, the higher the value of the variable, the higher the pitch of the sound, but, there is another modulation that could be chosen [22], that is modulating the volume of the sound with the variable fluctuations where the higher the value of the variable, the higher the volume of the sound.

In order to choose the modulation method, an experiment was held in the Product Delivery Centre room, a well insulted room with a low background noise, changing the algorithm that plots the sound in order to use the volume-modulation method, making the frequency keep stuck in the correspondent C note of each variable (C2, C3, C4, C5, C6, C7 and C8). Plotting just one variable at a time, and following its behavior with the visual log at sight, choosing the desired channel, the same variable was played in different frequencies, being modulated with the volume variances.
Instead of modulating the frequency by the use of the available 76 MIDI notes, they were modulated using the 127 levels of volume given by the software.

Engineers and geoscientists were invited to test both methods with the presence of the author all along January-February 2012. Twelve of the testers (included the author) that are all of them, concluded that even though theoretical volume resolution was 68% higher than notes resolution (128 vs. 76 available levels for modulation), modulating the volume instead of the frequency the resolution of the information being "plotted" was highly reduced.
No one of the testers was able to identify or compare differences more than ten times higher than they did identify and compare successfully when modulating the frequencies.

Grayed intervals in the figure 5 show those variable fluctuations not able to be distinguished using Volume-based modulation, but able to be distinguished using frequency-based modulation.
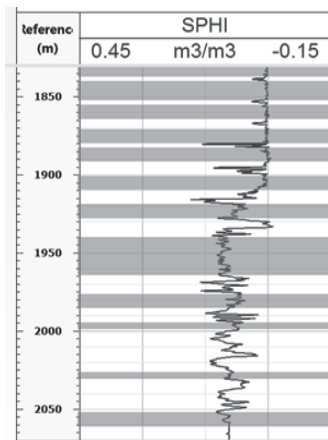

Figure 5 : Intervals in which users were not able to distinguish variances using volume modulation, but able using frequencies modulation.

As a result of the tests done, the modulation chosen was the frequency-based one, that gives more perceptual – definition rather than the volume-based one; even though that frequency discrimination learning curve for an auditory user takes more time than the intensity discrimination one [26].

But, despite the fact of the low-resolution of the volume-based modulation, its use brings another dimension that could be used in the future to convey certain variables values, so in future versions of the software, a couple of variables are going to able to be volume-modulated too.

There is a special modulation method, which is not in fact a modulation itself and is not related to the sonification technique, but it was advised by a blind user, that is the reading by a text-to-speech engine each one of the selected variable-values, and, instead of playing the musical instruments, the values are read aloud by the software.
This method does not apply to the conference aim but, was found as a great help for the user who asked for it.

6.   SOFTWARE USER INTERFACE DESIGN

The software used for coding was Visual Basic .NET Express, which is the one the author feels more comfortable working with.
The main form of the program allows the user to select which variables sonify choosing from the list of the variables found in the files being analyzed.

Also, user can choose which musical instrument will play each one of the desired variables , in the example, the tool-head

tension is being played by strings, the magnetic resonance porosity is played by an acoustic guitar, the gamma ray counts is played by an organ, etc.

The whole extended-MIDI instrument list is available to be used for playing any variable in its correspondent drop-down list. [24]

Volume and scales of each individual variable can be customized from the text-boxes in the main application form.
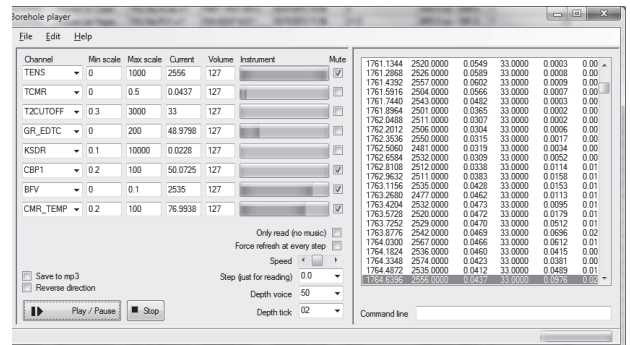

Figure 6 : Application GUI

In the main application form, scales are showed for each variable, and minimum and maximum default values for each variable that can be sonically plotted were defined by default to make them match with visual scales in the plots, but they can be customized too in order to allow small changes be heard with more sonic definition.

From this form, user can perform two other automatic scaling methods: the first one consists in automatically choosing maximum and minimum values for the scales by the analysis of the whole dataset, looking for the highest and the lowest value for the selected variable, letting top and bottom scale be these values; the second one is similar to the first, but, instead of giving the higher and the lower found values, the scales are set with the average measured value minus three times the standard deviation for the variable (for the lower), and plus three times the standard deviation for the upper scale value.

The idea behind the design of the interface is that every action that is done using the mouse must be done also by the use of the command line interpreter [27], placed in a text-box down to the right in order to let user write the commands instead of using the mouse. A set of instructions that can be used so far with the command line interpreter are in a list under the Help Menu.

No matter where the focus is, if the user presses the "Home" key of the keyboard, the focus is automatically set to the command line textbox.

Enabling or disabling the plot of a variable, playing the log, stopping the play, do a loop between certain depth intervals are some of the commands that can be entered by the use of the interpreter.
A file with the .wav stream created during the playback of some log can be produced by checking the check-box "Save to wav",

originally was though to create mp3 files but, for legal reasons I have to use another library to save the sounds.

Files saved are really big, so I have to improve this module for future versions in order to produce smaller files, and also let the user decide the kind of file (midi, wav, mp3) he wants to have.

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