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Simulating Sonic Scanner responses in an interactive Web-based High Performance Computing environment

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A new Wireline borehole acoustic tool allows recording a large amount of data about the geological formation. This is a blessing in disguise, as we are now discovering new features on the acoustic logs that have never been observed before; only rigorous modeling can help properly interpret the data. Invariably, it is difficult to learn quickly how to run a modeling code, set the parameters properly, and be able to detect possible errors in the input. In addition, complex modeling requires high power computing resources, which are not always readily available to the user. To address these issues, we developed a prototype of a multi-tier Web-based log modeling environment where the acoustics simulator is easily accessible from the common Web browser. The user builds the subsurface model in an intuitive interface and submits the simulation job to a remote high performance cluster. The computed and analyzed waveforms are presented in the browser using Scalable Vector Graphics and Adobe† Flex† in a variety of customizable displays. In addition, we made a programmatically accessible Web service available to application developers who desire to build their own interpretation applications using the Sonic Scanner simulator engine.

1 Introduction

Thanks to its plurality of receivers and transmitters and its high waveform quality, a new wireline acoustic tool allows accessing the properties of the formation in a novel way [1]. The drawback of this improvement is that we are now discovering new features in the acoustic logs and waveforms never before observed. This makes it difficult to understand the recorded data and provide the appropriate interpretation. Only rigorous physics-based modeling can help overcome this challenge.

Learning how to run a modeling code, set the parameters properly, and detect possible errors in the input, takes a non-trivial amount of time. In addition, complex modeling requires high-power computing resources, which are not always readily available to the users. There are also difficulties related to obtaining the “right” version of the modeling code and preventing "version proliferation” in large organizations.

All these reasons are making it difficult to model and interpret complex borehole acoustic data. Therefore, we found that there is a need for an architecture enabling interpreters to easily perform sonic simulations in a consistent and systematic way. We built on the earlier work of Polyakov et al. [2]. The novelty of this system lies in the simplicity of creating the desired formation model; running forward modeling and inversion remotely from any location via the Web; and the high efficiency of the parallel computing execution framework [3].

We present here how we extended the capability of the existing system to model the borehole acoustic tool in various environments and describe features of the prototype that enable modeling the acoustic tool in most of the conditions where it is run today. Finally, a case study scenario is presented.

2 Web-based modeling and inversion concept and architecture

We developed in research a prototype of a convenient Web-based platform for accessing log modeling and inversion engines. It has been initially implemented for Resistivity, sonic, and nuclear tools, and thanks to the modularity of the implementation, has the possibility of incorporating new modeling codes easily.

Physics-based log modeling in complex formations—borehole acoustic, for example—is computationally intensive and often necessitates the use of a fast computer to achieve a “while you wait” or “just in time” performance. The latter is particularly important for field operations where multi-million dollar decisions can depend on the modeling results. By placing the simulation code on a high-performance cluster and making it accessible via the Web, it is possible to achieve the desired performance without placing heavy demands on the user’s machine. Furthermore, a Web browser-based application needs no installation on the user’s workstation; any authorized person on the Internet can access the application through a common Web browser simply by following a Universal Resource Locator (URL).

Recent advances in Service Oriented Architectures (SOA) infrastructure [4,[5] have created another opportunity for Web-based modeling. In addition to providing access to the application for the *users* through the Web page, we can also enable networked *applications* to call the simulator library as a Web service, using remote communication protocols, without having to replicate it for every “consumer” application; when the library routines are called, the computation is performed on a remote server. Moreover, the application developer does not need to make any assumptions about the hardware and software configuration of the communicating systems, since all the information exchange is performed in a standard Extensible Markup Language (XML) format—SOAP[6]—over standard network protocols (such as HTTP). Thus, the developers can worry less about compatibility of their code with the simulation engine and focus instead on the science of log interpretation. As the updates are made to the service, all

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client applications benefit immediately. This eliminates the need for distributing and maintaining various code versions. Fig. 1 summarizes the system architecture.

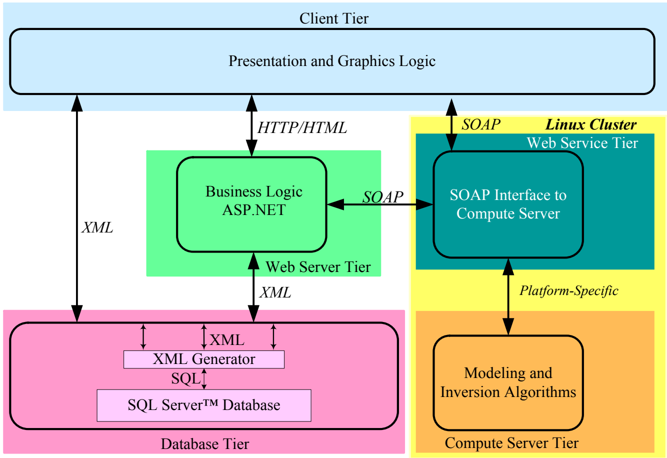

Fig. 1 Schematics of the system architecture.

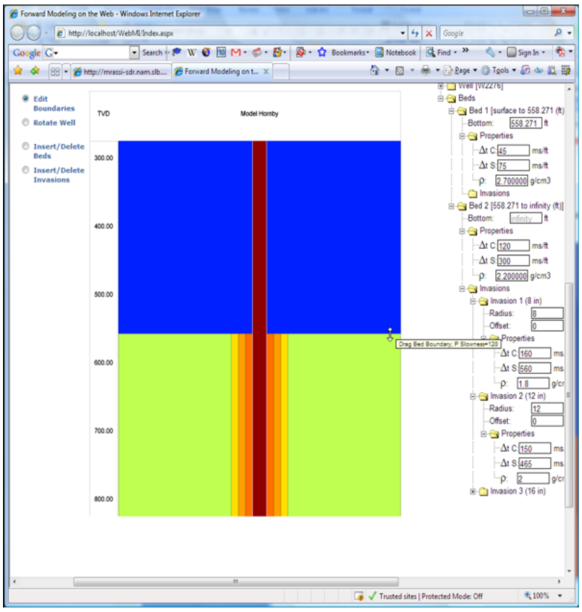

Fig. 2 Formation model can be constructed and edited interactively in the Web browser.

3 Web-based sonic log modeling

The integrated system described above allows modeling of borehole acoustics data for various tool and formation models. Here, we present the essential components (such as formation layering, material properties, tool configuration, etc.) that comprise our models.

3.1 Formation modeling

Layer thickness and physical properties, such as acoustic velocity and density, are the fundamentals of the formation model. The system allows interactive entry and editing of these as illustrated by Fig. 2 (material properties—in this case, compressional slowness—are mapped to color), as well as loading the entire model from an external file. In addition to these, borehole properties: diameter, inclination, and mud slowness, can be easily specified. The latter is a key parameter controlling acoustic wave propagation in a fluid-filled borehole, and yet, no direct measurement of it exists today. Therefore, being able to model various mud slowness conditions dramatically helps understanding the recorded data. Increasingly, acoustic tools are run in deviated wells, so modeling the well inclination is also of great interest; the inclination can be easily changed from the browser interface by simply rotating the well graphically.

Another subject of great interest to log analysts is modeling of acoustic tool responses in cased boreholes [7], as deep offshore wells are rarely logged in open hole today: oil companies prefer to case the well as soon as the drilling is finished, in order to avoid any wellbore stability issues. The Web-based system allows adding the casing to the model and specifying its properties (size, acoustic velocity, eccentering, etc.) either manually or by selecting from a catalogue of standard casing types.

One of the key aspects of cased hole acoustics modeling is the properties of the cement; similarly to casing, cement types with their respective properties are defined, so that the user can select the expected cement type, and have all the parameters chosen automatically. In case of exotic cement, an expert user has the capability to set its properties manually.

Another indispensable component of cased hole modeling is defining what is called the bonding conditions, which represent the boundary conditions between the casing, the cement, and the formation. There are several possible bonding conditions, mainly depending on the cement, and we usually categorize them as follows [8]:

- Well bonded casing (steel, cement, rock: SCR);
- Micro annulus between steel and cement (steel, water, cement, rock: SWCR);
- Micro annulus between cement and formation (steel, cement, water, rock: SCWR);
- Unbonded casing with fluid instead of cement (steel, water, rock: SWR).

With the described capabilities, we are able to model most of the realistic scenarios in both open and cased hole.

3.2 Tool modeling

One cannot simulate a tool response without defining the acquisition parameters: tool geometry (number of receivers, source-receivers distance, etc.) and the type of source excitation used in the acquisition.

The first fundamental parameter of the tool geometry needed for log modeling is the number of receivers in the array. In addition, the inter-receiver spacing can be changed if one desires to investigate the effect of spatial sampling of the receiver array on the waveforms acquisition. It is also possible to set the so-called TR-spacing; i.e., distance between the transmitter and the first receiver of the array. Varying this parameter, one can investigate, for example, the effect of TR-spacing on the penetration of monopole head wave into the formation (note that the latter is possible only for decreasing slowness profile [9]).

In addition to the tool geometry model, there is a class of parameters related to the source excitation. In a fluid-filled borehole, it is possible to excite various types of source signal [10]. The most common ones in the industry are the *monopole* high and low frequency, and the *dipole*. The two monopole modes are typically used for fast and intermediate formation, whereas when the formation becomes slow (i.e., the formation shear velocity is slower than that of the borehole fluid), the dipole excitation is used. The Web-based modeling system allows selecting predefined commercial configurations of the tool geometry and the excitation mode; if desired, the settings can further be changed manually for use in what-if scenarios.

3.3 High-performance simulation and analysis of results

Once the formation, the borehole, and the tool models are defined, the user specifies the logging interval and invokes the compute action, which submits the simulation job to the remote high performance cluster. Advanced users have access to the full set of control settings for the simulator, such as size and spacing of the finite difference grid; time sampling interval; various boundary conditions; etc.

The parallel computing component of this architecture is a fit-for-purpose framework, whose objective is to make the forward modeling and inversion code execution as fast as possible, as geoscientists often have to take real-time decisions based the log modeling results. The system exhibits minimal parallelization overhead and achieves near theoretical speedups on clusters with hundreds of compute nodes [3]. The user does not have to monitor the simulation process; one can disconnect (close the browser) at any time and reconnect later to inquire about the status of the job. Upon completion, the synthetic logs can be viewed interactively in the browser, while the numerical results of the simulation (computed waveforms) can be downloaded as a text file.

Sonic waveforms recorded with a new wireline acoustic tool are quite complex, as outlined above. It is common to analyze such waveforms with an array processing method based on matrix pencil technique [11] to obtain slowness and attenuation as a function of frequency; this method is usually called "*dispersion analysis.*" In the spirit of relieving most of the computing burden from the log analyst and automating the routine part of the analysis process, we have implemented the entire waveform analysis chain on the server tier of the system.

The matrix pencil algorithms were readily available to us as MATLAB‡ code; however, to run MATLAB on the server on-demand at any time for any number of users would mean having a substantial reserve of MATLAB licenses. We solved this problem by implementing the server-side execution environment for MATLAB code using Open Source Octave [12] application, which is compatible with most MATLAB scripts. To invoke the dispersion analysis chain, the user selects "Analyze Waveform" option in the browser interface; the request is sent to the server to invoke Octave scripts on the selected set of waveforms, and the computed slowness and attenuation series are streamed back to the browser. The results are then presented in highly interactive plots generated with Adobe† Flex† (Fig. 3 and Fig. 4)

‡ Registered trademark of the MathWorks Incorporated.

4 Case study example

In this section a modeling example is performed using the Web modeling capabilities presented above. The model, initially proposed by [13] is composed of two main parts (Fig. 2). The upper one is a homogenous layer with a monopole slowness of 45 μs/ft. The second part is an altered formation comprised by four vertical layers with the compressional slowness varying from 160 μs/ft near the borehole up to 120 μs/ft at the deepest radial position. The borehole, eight inches, is filled with a fluid, whose slowness is 205 μs/ft. The total depth size of the profile is over 300 ft.

In this paper, only the results obtained with a dipole source will be presented. Results obtained for a monopole high and low frequency source will be presented at the conference.

The simulation was run for 300 ft logging interval with a sampling rate of 0.5 ft, for a total of 601 measurement points. This particular job was able to reserve 154 processors on the high performance cluster and completed in approximately 56 minutes. As stated above, our system has near theoretical efficiency, which means that if a single processor was used for this simulation, the job would have taken about five days.

Figures 4 and 5 show the waveforms and related dispersion curves, respectively, obtained for a dipole excitation at two points, one in the altered and one in the non-altered zone. The low frequency part of the dispersion curves, i.e. the zero frequency limit, gives an estimate of the shear slowness of the formation. It is easy to see that we are observing the latter as expected. The difference between the dispersion curves obtained from altered and non-altered zone is clearly visible.

The importance of these results is in illustrating the effect of alteration on dipole dispersion curves. Modeling can therefore provide the critical quantitative information on how to interpret dispersion curves in altered formations.

Note that it is also possible to invert dipole dispersion curves to get an estimation of the altered profile [14]. Such inversion algorithm has not yet been implemented into the present workflow.

Conclusion

Complexity of reservoirs is making data interpretation more and more difficult. The only way to help log analysts better understand the data they are studying is to provide them with the modeling tools capable of simulating various subsurface types and logging conditions.

However, being able to model borehole acoustics responses is not an easy task for non-expert users. Choosing the right parameters for the modeling code, the geometry of the acquisition device, complex formation types, etc., is a challenging exercise. Simulation often takes a very long time on a single-user desktop.

In order to overcome these issues, we developed and presented in this paper a system for efficient and ubiquitous simulation of acoustic logging tool responses via the World Wide Web. The simple interface enables to generate complex models, while high computing power allows getting results in a fraction of the time that would have been spent using a desktop computer. In addition to these modeling capabilities, the software provides an easy tool to analyze the simulated waveforms.

In this paper we mainly focused on the forward modeling approach. We expect to extend the system capabilities in the future by providing integrated inversion algorithms within the same framework.

Acknowledgments

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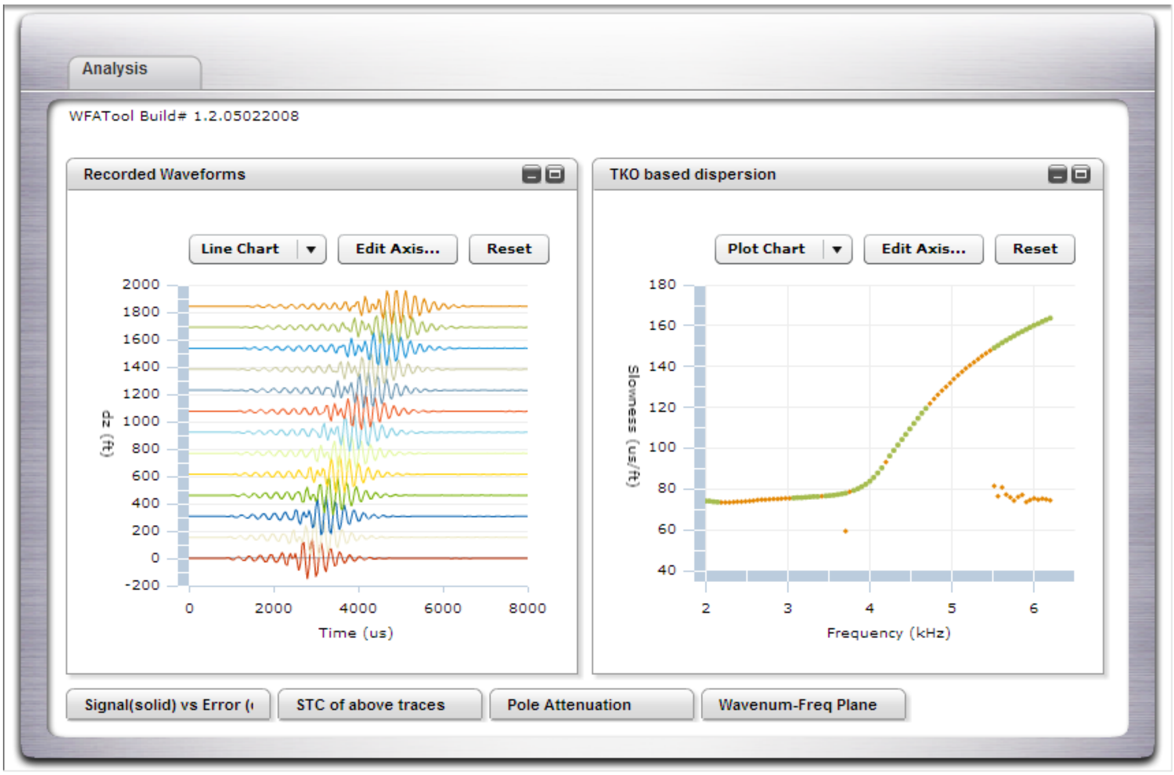

Fig. 3 Waveforms and related dispersion curve in the homogeneous zone in the case of a dipole source excitation mode.

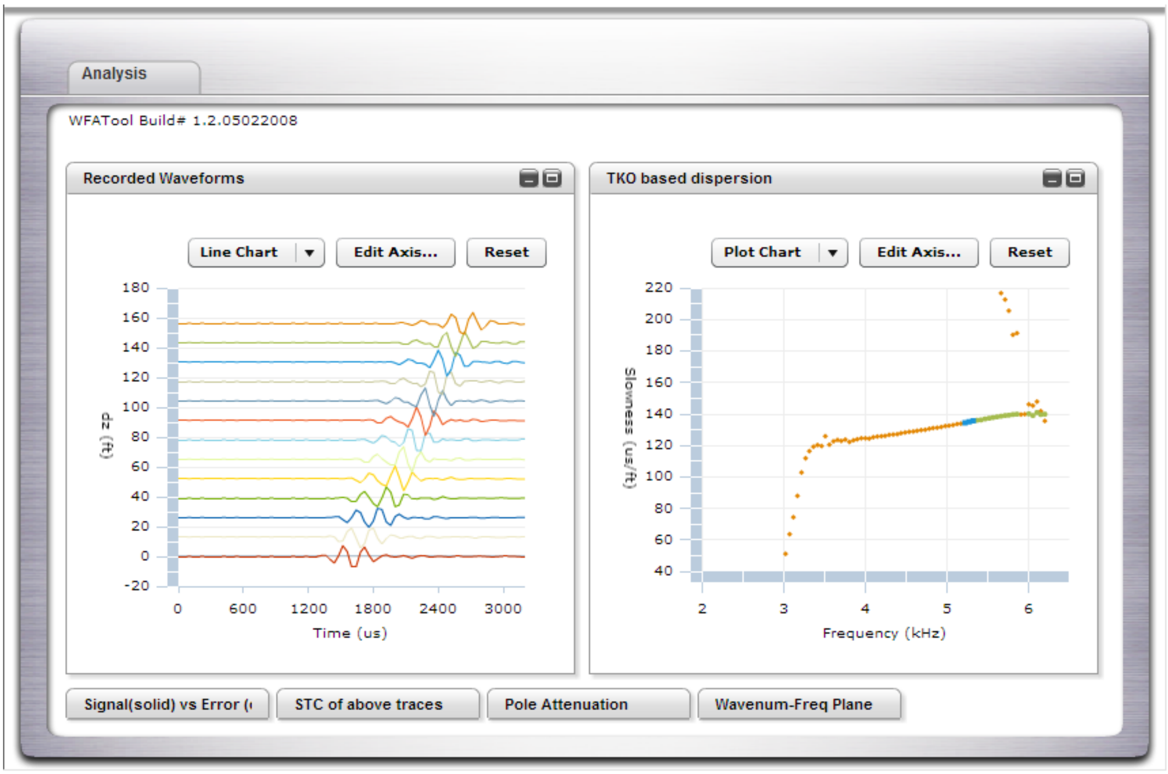

Fig. 4 Waveforms and related dispersion curve in the altered zone for a dipole source excitation.