Support Vector Machine (SVM)-based Geostatistical Inversion: An Integrated Solution to Honor Well-log Data and Seismic Attributes

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Summary

This work describes an integrated solution for geostatistical inversion to honor well-log data and seismic attributes based on Support Vector Machine (SVM). The well-log data vary greatly in depth domain with higher vertical solution, and the environment and boundary effects of well-log data usually have been corrected in order that the log records at any depth are the contributions from lithology and hydrocarbon. However, the seismic data are recorded in time domain with poor vertical solution. Seismic data d (t0) is usually assumed to be the convolution of a wavelet w (t) with the reflectivity r (t). The convolution model means the seismic data at any given time are the contributions from a time range rather than a point like well-log records.

How to incorporate two different domains (time and depth) dataset and two different measurement systems is crucial for our reservoir characterization modeling. The seismic post/pre-stack inversion is one of most important step and gains very popular at oil and gas industries. However only a very small part of both well-log and seismic info can be integrated for our reservoir modeling at current inversion procedure, such as compressional velocity, shear velocity and density are common for AVO application. In fact there are more reservoir parameters evaluated from well-log, such as porosity, volume of shale and water saturation and there are more time-domain and frequency-domain attributes extracted from seismic gathers. It is challenging for us to integrate and honor all these dataset for the reservoir characterization modeling. This paper will present our geostatistical inversion solution to honor well-log data and seismic attributes based on Support Vector Machine (SVM).

Our geostatistical inversion solution is an integrated approach. Firstly, we need to evaluate well logs to calculate the reservoir parameters, such as porosity, water saturation and volume of shale. Secondly, the reservoir parameters and well logs will be converted from depth-domain to time-domain which will be consistent with seismic dataset and seismic attributes. Thirdly, it is crucial to extract time/frequency-domain seismic attributes from stack seismic dataset and pre-stack seismic gathers. Lastly, a Support Vector Machine (SVM) will help us to honor seismic attributes and well-log data to propagate log-derived reservoir property from borehole to 2D/3D space to generate the reservoir characterization model.

The fundamental difference from current seismic inversion is that our approach can handle the anisotropy of reservoir property and directly invert reservoir property from both post-stack and pre-stack attributes and from both time-domain and frequency-domain attributes.

The integrated solution for geostatistical inversion has demonstrated positive results during model test and field dataset application.

Petrophysics Analysis

Because our integrated solution for geostatistical inversion heavily depends on well-log data and well-log evaluation, a multi-objective optimization will help us to evaluate the porosity, volume of shale, water saturation and permeability from well-log data. The gross sand and net pay can be classified using log-derived property cutoff, such as porosity, volume of shale and permeability. In order to incorporate well-log data to seismic attributes, the synthetic seismograms can be generated from logs to better match the seismic data along well trajectory and then the well-log data will convert from depth-domain into time-domain logs.

Seismic Attributes

Traditionally seismic technology is used by geologists and geophysicists who interpret the data to map structural traps that could potentially contain hydrocarbons. The seismic attributes from post-stack and pre-stack dataset and from time-domain and frequency-domain could be used to propagate the log-derived property to seismic 2D or 3D space. Seismic attributes fall into two broad categories: time-domain attributes and frequency-domain attributes. Both time-domain and frequency-domain attributes can be extracted from post-stack seismic and AVO/AVA/CDP gathers, which could be before-nmoed gathers and after-nmoed gathers. If seismic dataset is stack data, instantaneous attributes (frequency, phase, amplitude) and spectral decomposition attribute can be generated. If seismic dataset are before-nmoed gathers, we present a method to extract radon-related attributes based on parabolic/hyperbolic radon transform. Also a pre-stack spectral decomposition workflow could help us to generate a series of hybrid seismic attributes from seismic gathers.

Spectral decomposition unravels the seismic signal into its constituent frequencies and amplitudes using a small window. It is very difficult to directly apply spectral decomposition to our pre-stack gathers. However, we present a workflow which will handle the seismic gathers. The workflow consists of Factor Analysis to optimize seismic gathers and then apply spectral decomposition to decompose the optimized traces.

SVM-based Geostatistical Inversion

SVM-based geostatisitcal inversion is based on Bayesian Inference and uses a Support Vector Machine (SVM) method to honor seismic attributes, well-log data and geological information. During the training phase, given a set of both time-domain and frequency domain seismic attributes with the corresponding well property target from available boreholes, the SVM will develop the mapping functions between seismic attributes {x} and well property {t}, such as porosity. The mapping functions can be describes:

$$t(x) = W \sum_{n=1}^{N} \omega_n K(\tilde{x}, \tilde{x}_n) + \omega_0 + \text{horizon constraint} + \text{space constraint} + \text{geological constraint}$$

Where { ω_n } are the model weights and can be determined during the training phase. $K(\tilde{x}, \tilde{x}_n)$ denotes the kernel function, such as Gaussian function. {W} is the attributes weight. The space constraint means the Cartesian coordinate system of both seismic and well. If well property is preferred orientation, the antistrophic setting, such as a ratio and angle, could be applied.

After the training phase, the SVM can propagate the borehole property onto 2D/3D seismic space using the seismic attributes and their constraint conditions and then to generate the reservoir model.

Our SVM-based geostatisitcal inversion method that makes it different from current seismic inversion is that our method works with both time-domain and frequency-domain attributes from post/pre-stack seismic dataset to directly invert the reservoir parameters, such as porosity, rather than other elastic properties which need to convert to log-derived properties for interpretation. Another fundamental difference from current seismic inversion is that our method can handle the anisotropy of reservoir property and consider the geological constrained conditions.

Examples

Figure 1 shows a model with six sand layers with different thickness and velocity. There are two wells available for our inversion. Figure 2 describes three before-nmoed gathers and Figure 3 is spectral decomposition hybrid attributes. Figure 4 demonstrates our geostatiscal inversion result integrated from seismic attributes and two wells. It seems the inverted result is reasonable compared with the model dataset. Also the field dataset have demonstrated the positive results.

Conclusions

An integrated solution for geostatistical inversion to honor seismic attributes and well-log dataset has been presented. Our SVM-based geostatisitcal inversion is fundamental difference from current seismic inversion, in which our approach can handle the anisotropy of reservoir property and directly invert reservoir property from both time-domain and frequency-domain attributes extracted from post/pre-stack dataset.

References:

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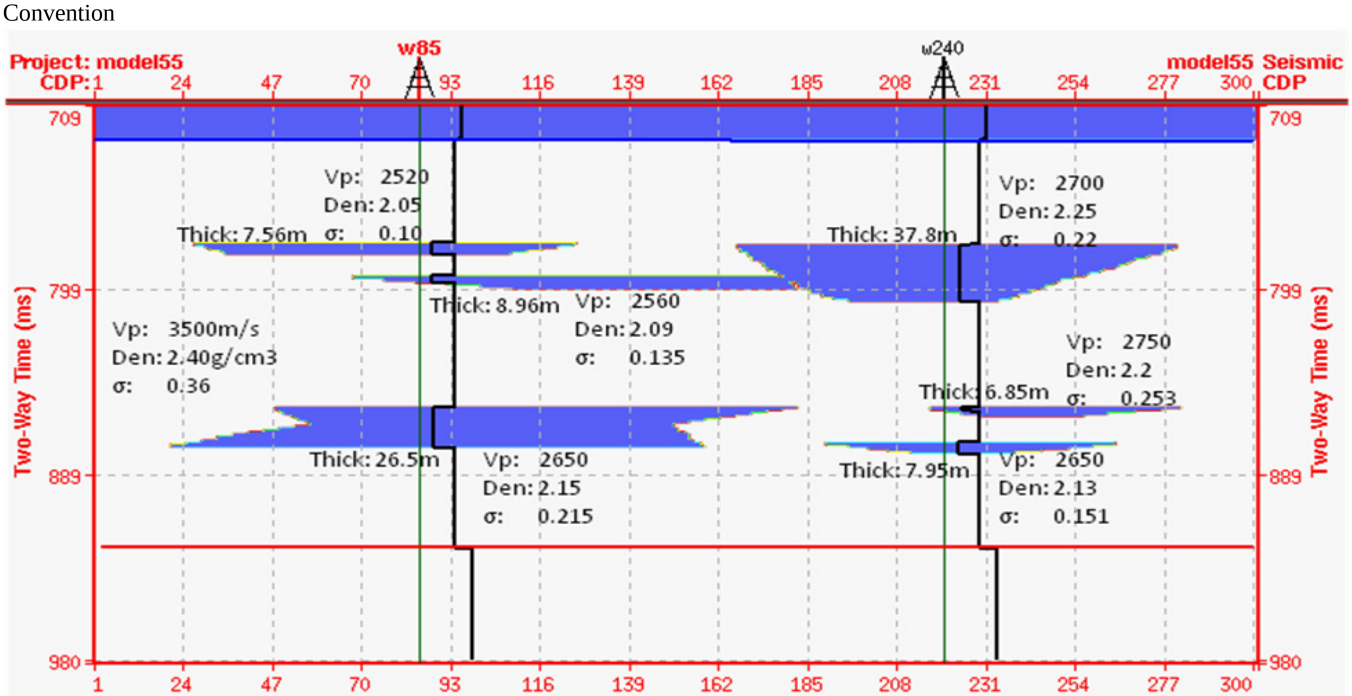

Figure 1: six sand layers and two wells

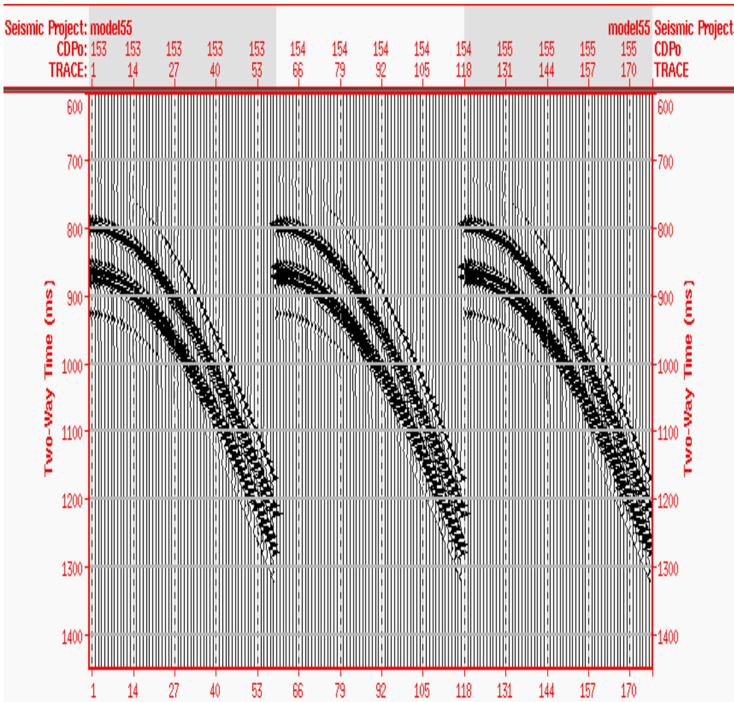

Figure 2: three before-nmoed gathers

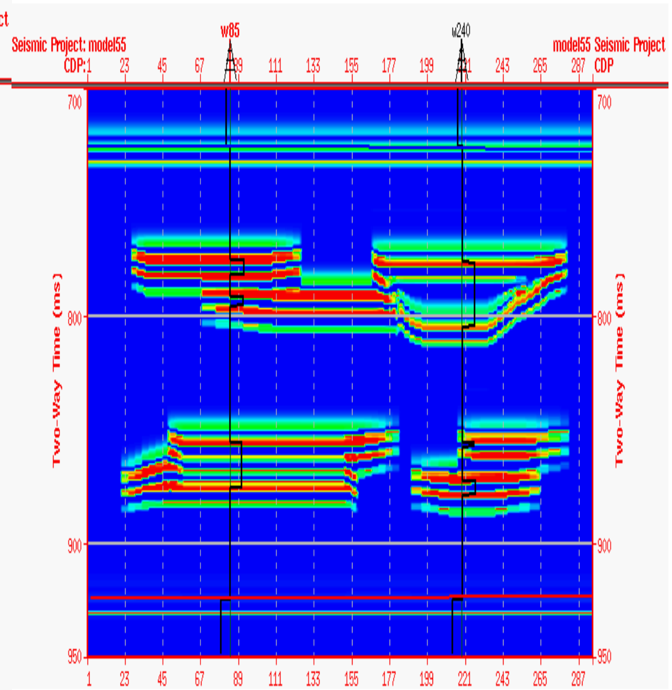

Figure 3: Spectral Decomposition Hybrid Attribute

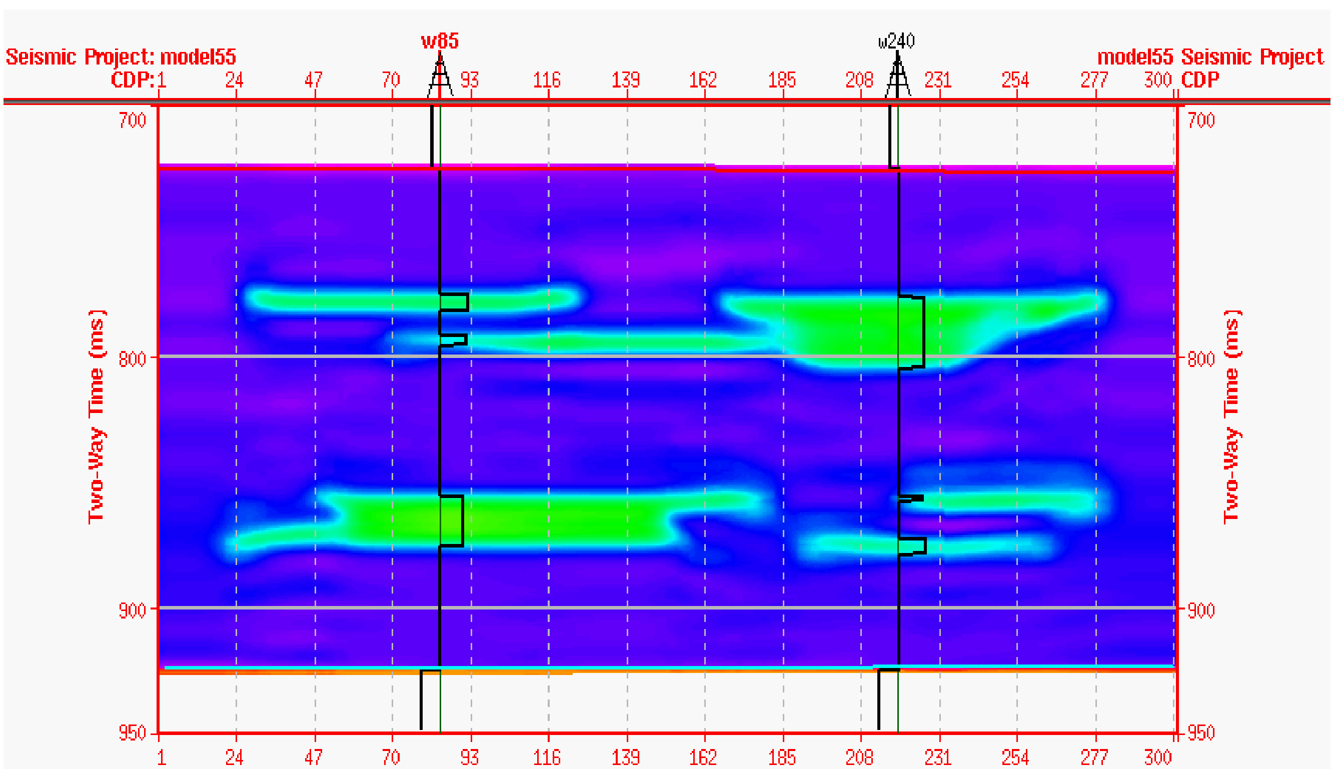

Figure 4: geostatistical inversion section based on seismic attributes and two well-log data