Analysis of the Pattern Correlation between Time Lapse Seismic Amplitudes and Saturation

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Abstract

The number of hydrocarbon reservoirs with available 4D seismic data has been increased recently, which provides opportunities for new research. This work presents prospects of our future study in analyzing spatial patterns between time lapse seismic data and saturation changes. This work builds upon previous research that has been started at Stanford University. Its novelty include using non-linear feature extraction technique, Kernel Principal Component Analysis, (KPCA), new synthetic reservoir model, and attempt to apply these methods on a real reservoir data set.

1. Introduction

Information obtained from seismic surveys is widely used in reservoir characterization as it can extract qualitative and quantitative data from a large area, whereas wells can provide only local data. Seismic data is often represented by seismic attributes, which depend on static (lithofacies, porosity) and dynamic (saturation, pore pressure, temperature) properties of a reservoir. Time lapse seismic data is used as a reservoir monitoring tool as it can provide information on fluid dynamics in the reservoir, which is based on the relation between variations of seismic attributes and changes in formation pressure and fluid saturation. Time-lapse seismic data has found its applicability in calibrating geological models, history matching, determining well locations, production optimizations, etc. However, not considering the favorable cases when fluid movement can be observed visually, it is of importance to establish a correlation between saturation changes and seismic data changes. Research in this area includes work by Wu, (2003, 2007) and this work presents the prospects of extension of that study.
The previous research produced good results and based on those results the further studies should be carried out to understand how correlation of spatial patterns between 4D seismic data and saturation could be improved and applied in the industry. The future study will be conducted on Stanford VI synthetic reservoir (Castro, Caers, and Mukerji, 2005), which is more complex “exhaustive” reservoir as compared to Stanford V that was used in the previous study. To improve correlation between change in water saturation and seismic amplitude in addition to linear multivariable techniques (principal component analysis and canonical correlation analysis) non-linear kernel principal component analysis will be used on the given data set. Finally after getting results from synthetic reservoir, this method will be applied on a real reservoir data, from the Norne field in the Norwegian Sea. Even though it is a challenge to perform analysis on a real reservoir data as it is not exhaustive and could have many imperfections in the data set, PCA and KPCA should help in reducing the noise derived from that inaccuracy, and improve spatial pattern correlations.

2. Previous work

2.1. Objective and results

The objective of the previous research was to quantitatively detect pattern correlation between seismic difference and the change in water saturation or water volume, then use this correlation to help in predicting future water saturation field. The direct point to point correlation between 4D seismic amplitudes and 4D saturation variables was very low (0.3), partly because of different volume support. However, spatial patterns of the principal components of both seismic time difference and saturation time difference showed good correlation of 0.7 and 0.8 from principal component analysis and canonical correlation analysis respectively. (Wu, 2003)

2.2 Stanford V synthetic reservoir

The second layer of Stanford V synthetic reservoir was used as reference “exhaustively” known reservoir to conduct the study. The Stanford V reservoir (Mao, 1999; Mao and Jounel, 1999) is a large 3D data set modeling a clastic reservoir made up of meandering fluvial channels with levies and crevasse splays in a mud background. The reservoir horizontal extent is 2.5 km EW and 3.25km NS, at a vertical depths varying from 613m to 1097 m. A flow simulation was performed on Stanford V to obtain water
saturation change over time and forward seismic simulation was performed to obtain seismic amplitude, which were used for the research.

3. Future research

3.1 Future work

In order to explore and understand better the spatial pattern correlations in time lapse seismic signatures and its applicability in the petroleum industry we are planning to accomplish the following tasks:

1. Review of the literature and scientific papers on the time-lapse seismic and kernel principal component analysis. Both should assist in understanding what progress has been made in working with time-lapse seismic data and how KPCA has been implemented in pattern analysis.

2. The preparation of the data set necessary for the study. Stanford VI is an exhaustive synthetic reservoir, which provides that data. For details on Stanford VI see appendix A. One of the issues in preparing the data set will be to match the results from the flow simulator which are in depth coordinates, and the results of the seismic simulator which are in traveltime coordinates. Careful time-to-depth conversions will be carried out to correctly tie the horizons in depth and time coordinates. For synthetic data, since the properties are exhaustively known, the correct seismic velocities will be used to make the ties. In real data, time-to-depth conversion can be a major source of uncertainty.

3. The implementation of KPCA on the spatial patterns of time lapse seismic amplitude and water saturation change over time. The previous work by Wu on finding the correlation between spatial patterns of 4D seismic and saturation changes produced good results while using PCA and CCA. However, both techniques are limited to linear combination of data values and statistics up to order 2, whereas spatial pattern may have non-linear features. In this case kernel principal component analysis (KPCA) could be used to relate spatial patterns between seismic and saturation time lapse variables. The description of the methods is provided in appendix B.

4. The sensitivity analyses will be conducted as well to understand how different parameters can affect correlation between spatial patterns of seismic amplitude and saturation change.

5. If considerable correlation is found during the experiments and what is the impact of different parameters on it is understood, then the next important step will be to predict water saturation from available time-lapse seismic data.
6. The final step will be to apply the methods to a real reservoir. Stanford VI is an exhaustive reservoir, hence it is a good tool to conduct the experiments and understand the processes. However, real reservoirs are more complex, the seismic data is imperfect, and reservoirs are not well characterized. Therefore the industry needs this type of technique to better use time lapse seismic patterns in characterizing changes in the reservoir condition.

3.2 Expectations from the research

We expect to have good results from this research. The dependence of seismic attributes on changes in fluid saturation exists and understanding how to find spatial correlation between them is very important. Moreover, understanding how this correlation could be found for time-lapse seismic attributes and how it can be applied for the prediction of water saturation is of importance. This study will help us to learn more about time-lapse seismic data and we hope that this knowledge will be beneficial for the academia and industry.

Even though we have certain goals for this research, we are sure that it will reveal many other challenging results, which will deserve attention from us and other researchers. It is very important to continue research in this area as it still needs exploration.

4. Conclusion

This paper presents future research work on finding correlation between spatial patterns of seismic data and water saturation, which can be used for prediction of water saturation based on seismic data. Previous work produces good results and demonstrates that there is a pattern correlation between seismic data and water saturation. However, this study needs to be extended as data obtained from time lapse seismic data is very important and it requires more exploration. KPCA is considered to be a good technique to work with image data and in most cases it outperforms PCA. Hence it will be very useful to apply it for pattern analysis. Finally this methodology should be applied in the real reservoir data set as its applicability in the industry is a final goal.
Appendix A

Stanford VI synthetic reservoir

The future research is going to be performed on a Stanford VI synthetic reservoir data set, (Castro et al., 2005) which exhibits more geologic channel structures, more realistic dimensions for current-day models and improved rock physics models compared to Stanford V. The Stanford VI reservoir is a three-layer prograding fluvial channel system, and its structure corresponds to a classical structural oil trap, asymmetric anticline with axis N15°E. The reservoir is 3.75 km in EW direction and 5.0 km in NS direction, with a shallowest top depth of 2.5km and deepest top depth of 2.7km. The reservoir is 200m thick and consists of three layers with thicknesses of 80m, 40m and 80m respectively. The Stanford VI is represented in 3D stratigraphic grid of 6 million (150x200x200) cells and the dimensions of the grid corresponds to 25m in the x and y directions and 1m in the z direction. (Fig.1)
prior to oil production and three time lapse seismic surveys acquired 10, 25, and 30 years after oil production (results from forward seismic simulation using trace by trace convolution model).

Reservoir simulation results are also part of this data set, which provided us with water saturation evolution over the reservoir production life. In order to perform reservoir simulation the model was upscaled using block average technique to 750 000 cells (75x100x100) and production was simulated for 30 years. (Fig. 2)

Figure 2. Water saturation from upscaled model after 10 (top left), 25(top middle) and 30 (top right) years of oil production. Seismic amplitude difference from upscaled model for 10(middle left), 25 (middle middle) and 30 (middle right) year of oil production. Seismic amplitude difference from upscaled model for 10(bottom left), 25(bottom middle) and 30 (bottom right) year of oil production. Source: Castro et al., 2005.
Appendix B

PCA and KPCA techniques

The central idea of principal component analysis is to reduce the dimensionality of a data set which consist of a large number of interrelated variables, while retaining as much as possible of the variation present in the data set. This is achieved by transforming to a new set of variables, the principal components, which are uncorrelated, and which are ordered so that the first few retain most of the variation present in all of the original variables. (Jolliffe, 1986). In this case PCA is used to extract principal components from seismic amplitudes and water saturation differences (in space and time) and then to find the correlation between the few first seismic PC’s and the water volume differences, or the few first PC’s defined on the water volume differences.

Initially PCA will be applied on the layer 2 of the Stanford VI, and then on the other layers separately as they represent different fluvial channels. To generate input images for PCA a moving window of size 5x5 grids will be used for each sub-layer of layer 2 as it was done in the previous research. There will be 3 input images generated for each sub-layer by assigning different values for the central grid of the window through the following calculations: 1) the center of the window is the same, 2) the center of the window is an average value of 9 grids located within 3x3 square, 3) the center of the window is an average value of 25 grids located within 5x5 square. This generation will result in having input variables equal to 3 times number of sub-layers in the layer 2. For example if we have 40 sub-layers in layer 2, then we multiply it by 3 and get 120 images representing layer 2. The final goal of PCA is to get few images (PCs) that can represent the whole layer in terms of the chosen property. In this case PCA is applied on seismic amplitude and water saturation difference over time. After obtaining PCs the correlation coefficient will be determined. This technique is used in the previous research as well.

Kernel PCA accounts for nonlinearity of spatial patterns. In kernel principal component analysis the data is mapped to higher dimensional feature space by using kernel function. Then PCA is performed in that space via kernel trick. (Scholkopf et al., 2002). KPCA is a very efficient technique and it found its applicability in many fields like visual processing tasks, image denoising, nonlinear regression, etc. We will also use sliding window to generate input parameters for KPCA. The principal components obtained from KPCA will be used to find the correlation between patterns. However, application of KPCA should be done carefully as it has its own difficulties. This technique can not be described fully in this proposal, but only its potential applicability for this study.
Reference:


