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Introducing a new textural attribute based on the anisotropy index – A case study: Salt dome

Mohammad Reza Mousavinezhad[1]; Amin Roshandel Kahoo[2*]; Mohammad Radad[3]

1. PhD Student, Faculty of Mining, Petroleum and Geophysics, Shahrood University of Technology, Shahrood, Iran.
2. Associate Professor, Faculty of Mining, Petroleum and Geophysics, Shahrood University of Technology, Shahrood, Iran.
3. Assistant Professor, Faculty of Mining, Petroleum and Geophysics, Shahrood University of Technology, Shahrood, Iran.

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Corresponding author: roshandel@shahroodut.ac.ir

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Extended Abstract

Summary

Accurate identification of subsurface structures, such as salt domes, is of high importance in hydrocarbon exploration. Conventional seismic data processing and interpretation methods, including common seismic attributes like coherence, curvature, and chaos, have limitations in the precise delineation of geological structure boundaries, such as salt domes, despite providing useful information. One of the novel approaches to overcome this challenge is the utilization of seismic data texture analysis, aiming to identify these structures by contrasting the textural features of the study area. Seismic texture can provide information about sedimentary facies, reservoir structures, and geological heterogeneities. In this research, inspired by the concept of anisotropy in layered media and the relative isotropy of salt domes, a new textural attribute titled the "gradient tensor anisotropy index" has been introduced. This attribute is developed based on the statistical analysis of the eigenvalues of the local gradient structure tensor, and its objective is to differentiate between regions with clear directionality (layering) and regions without a dominant orientation (such as salt domes). To evaluate the performance of this index, two-dimensional (2D) seismic data related to a salt dome in the Strait of Hormuz have been used, and the results have been compared with the conventional entropy and chaos attributes. The obtained results show that the proposed anisotropy index has a high capability in precisely delineating the salt dome boundaries and, especially in appropriate window sizes, provides more consistency with human interpreters' interpretation. This attribute is more stable against noise and also operates independently of dip calculation. Therefore, it has less computational error. Furthermore, due to its structure-oriented nature, it possesses higher computational efficiency compared to traditional methods. Finally, the gradient tensor anisotropy index can be used as an accurate and effective tool in the textural analysis of seismic sections toward achieving the goal of automated interpretation of subsurface structures, especially salt domes.

Introduction

Accurate identification of subsurface structures, such as salt domes, is of high economic and exploratory importance due to their key role in the accumulation of hydrocarbon resources. However, conventional seismic data processing and interpretation methods, including common seismic attributes like coherence, curvature, and chaos, face limitations in the precise delineation of the boundaries of these geological structures, despite providing useful information. These limitations have increased the necessity of using faster, more cost-effective, and more efficient exploratory methods.

One of the novel approaches to overcome this challenge is the utilization of seismic texture analysis. Seismic texture, by focusing on spatial patterns and the distribution of amplitudes, can provide vital information about sedimentary facies, reservoir structures, and geological heterogeneities. In this regard, this research, inspired by a key physical contrast—namely the concept of anisotropy in layered sedimentary media and the relative isotropy of salt domes, introduces a new textural attribute titled the "gradient tensor anisotropy index". The main objective of this attribute is to provide a quantitative criterion for differentiating between regions with distinct directionality (layering) and regions without a dominant orientation (such as salt domes).

This attribute is developed based on the statistical analysis of the eigenvalues of the local "gradient structure tensor". To evaluate its performance, real 2D seismic data related to a salt dome in the Strait of Hormuz was used, and the results were quantitatively and qualitatively compared with two conventional textural attributes (namely, gray level co-occurrence matrix or GLCM-based entropy and chaos). The results show that this index is not only more stable against noise but also has less computational error due to its independence from dip calculation. Finally, the prospect of this research is to provide an accurate, effective, and computationally efficient tool for the purpose of automated interpretation of subsurface structures, especially salt domes.

Methodology and Approaches

The main approach of this research is seismic texture analysis, which is based on the physical contrast between the relative "isotropy" of salt domes and the "anisotropy" of layered sedimentary media. In this study, the seismic section is considered as an image in which the variations in seismic amplitude are equivalent to the changes in pixel intensity. The algorithm operates based on the "gradient structure tensor". The computational process is as follows: first, a moving analytical window is applied to the seismic data. Within each window, the horizontal and vertical gradients are calculated. Then, the covariance matrix of these gradients, which is the gradient structure tensor, is formed. Using principal component analysis (PCA), the eigenvalues of this matrix are extracted. The new "anisotropy index" is subsequently calculated based on the normalized difference of these eigenvalues. This Euclidean normalization process is used to reduce the attribute sensitivity to signal intensity and noise. All coding, analyses, computations, and visualizations for this study were fully implemented and executed in the MATLAB software environment. This method was tested on a real 2D marine seismic dataset from the Strait of Hormuz, and its performance was evaluated using various window dimensions, from 3×3 to 17×17. To validate this attribute, qualitative and quantitative comparison methods were used. In the qualitative assessment, the results were visually compared with the salt dome boundaries that had been interpreted by three professional interpreters. In the quantitative assessment, the F1-Score metric was used to measure accuracy. The performance of the proposed index was benchmarked against two conventional textural attributes, namely entropy (based on GLCM) and Chaos. This quantitative evaluation process involved converting the outputs of each attribute into binary models using thresholding and morphological methods, which were then compared with the binary model derived from the manual interpretation.

Results and Conclusions

In this paper, based on the isotropy analysis of seismic amplitude variations in a local analysis window, a new textural attribute titled the anisotropy index was introduced. The results obtained from the analyses and real data showed that:

1. The anisotropy index attribute shows the salt dome with lower values than the surrounding sedimentary layering, due to the lack of a specific orientation within it.

2. The gradient tensor anisotropy index, in comparison with the chaos and GLCM entropy attributes, has a higher capability in accurately differentiating the salt dome from its surrounding layering and determining its boundaries, and it shows better conformity with manual interpretations.

3. Unlike the two aforementioned attributes, the anisotropy index is independent of dip calculation and, consequently, is unaffected by errors arising from uncertainty in dip estimation.

4. Due to not requiring dip calculation and the selection of a structure-oriented analysis window, the computational efficiency of the anisotropy index attribute is better compared to the above-mentioned two conventional attributes.

5. Given that the derivative is one of the pillars of the anisotropy index attribute calculation, the effect of noise will be dominant in small windows, and therefore, it is better to use medium and large-sized windows for real seismic data.

6. The anisotropy index attribute provides higher accuracy in larger windows compared to the other two attributes. This fact indicates that, on one hand, this attribute has greater resistance to noise, and on the other hand, increasing the window size does not have a considerable effect on reducing its resolution power.