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Developing an automatic algorithm for salt dome detection based on seismic attributes and mathematical morphology operators

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Extended Abstract

Summary

Salt domes are complex geological bodies that often produce chaotic reflection patterns in migrated seismic data, which makes their interpretation time-consuming and uncertain. This study proposes an automatic and efficient method to detect salt dome boundaries in three-dimensional (3D) seismic data and to generate a 3D salt-dome model. The approach is based on integrating a seismic attribute with 3D mathematical morphology operators. In the first step, the seismic attribute is computed. After normalization, the attribute volume is converted into a binary volume using an automatic thresholding scheme. A sequence of morphological operations, including opening (for noise suppression) and hole filling (to restore internal continuity), was then applied to obtain a refined 3D salt body. The algorithm has been applied on a 3D seismic dataset in southern Iran, within the Strait of Hormuz. Three texture-sensitive attributes comprising of energy, entropy, and chaos have been tested. The results indicate that the proposed workflow can achieve boundary detection accuracy close to manual interpretation while requiring only about 30 seconds for the morphology-based stage to generate the 3D salt dome body. Quantitative evaluation further shows that texture energy yields the best performance among the tested attributes, whereas the chaos attribute performs the weakest.

Introduction

Salt movement commonly forms steeply dipping and geometrically complex structures that complicate seismic velocity modeling and migration. Because salt is typically impermeable, it can act as an effective barrier to hydrocarbon migration, and thus, provides favorable conditions for trapping and accumulation of oil and gas. Accurate identification and modeling of salt domes are therefore critical in petroleum geoscience, particularly for subsurface reservoir characterization. In migrated seismic data, salt domes typically exhibit irregular and chaotic internal reflections, producing a seismic texture that differs from adjacent layered sediments. A variety of seismic attributes such as energy, similarity, entropy, and chaos can help highlight these textural contrasts. Because salt interpretation can be formulated as a structural segmentation problem, image-processing tools are applicable. Mathematical morphology, originally developed for binary images and later extended to higher dimensions, provides a powerful framework for shape-based filtering and segmentation. This study builds on this idea and proposes an automated 3D workflow that combines seismic attributes with morphological operators to deliver a 3D salt dome model with acceptable accuracy and a practical runtime.

Methodology and Approaches

The proposed workflow consists of two main stages: (1) seismic attribute analysis and (2) 3D mathematical morphology-based image processing. First, seismic attribute is computed from the 3D seismic volume: chaos (a measure of local disorder and low coherence), texture energy, and texture entropy derived from a 3D extension of gray-level co-occurrence matrix (GLCM) analysis. Second, each attribute volume is normalized, and then, converted to a binary representation using an automatic thresholding method. The threshold is selected by analyzing the histogram of voxel intensities to separate foreground and background in a data-driven manner, avoiding manual parameter tuning.

Morphological opening is then applied to suppress isolated noise and small artifacts around the salt body. Because binary salt volumes may contain internal gaps due to attribute variability and seismic texture heterogeneity, a hole-filling operator is finally used to restore continuity within the detected salt region. The result is a refined 3D salt dome volume that can be visualized and assessed as a final model.

Results and Conclusions

The method was evaluated on a 3D seismic dataset in southern Iran. The studied volume contains 280 inlines, 311 crosslines, and 426 time samples with a 4-millisecond sampling interval. A qualitative comparison between the seismic texture attributes used in this study indicates that texture energy delineates salt boundaries more clearly than texture entropy, and texture entropy performs better than chaos in outlining the salt body. Comparing the results of the automatic method used in this study for boundary detection against the manual interpretation on a selected inline demonstrates that the automatic method reproduces the salt dome outline having good agreement with the results of the manual interpretation. For quantitative assessment, a symmetric surface-distance metric was used to measure the average geometric discrepancy between the extracted boundary and the manually interpreted boundary. The results confirm that texture energy provides the most accurate boundary detection, while chaos yields the least accurate outcome. In terms of computational efficiency, the morphology stage implemented in MATLAB software environment produced the final 3D salt model in approximately 30 seconds on a standard laptop. This runtime is considered practical for industrial-scale datasets. Overall, the study demonstrates that combining seismic texture attributes with 3D mathematical morphology offers an effective and fast route to automated 3D salt dome modeling, reducing interpreter subjectivity and enabling scalable processing of large seismic volumes.