Title:
Salt dome delineation using edge- and texture-based attributes

Author(s):
Muhammad Amir Shafiq*, Yazeed Alaudah, and Ghassan AlRegib
Center for Energy and Geo Processing (CeGP),
School of Electrical and Computer Engineering,
Georgia Institute of Technology,
Atlanta, GA, 30332
*amirshafiq@gatech.edu

Summary:
A lot of research has been done in the past to capture seismic features based on different edge- and texture-based attributes. In this paper, we apply a phase-based edge detection algorithm, namely phase congruency (PC), and a texture-based algorithm, namely gradient of texture (GoT), to localize a salt dome within SEAM dataset. Phase congruency (PC) can highlight small discontinuities in images with varying illumination and contrast using the congruency of phase in Fourier components. PC can not only detect the subtle variations in the image intensity but can also highlight the anomalous values to develop a deeper understanding of post-migrated seismic data. In contrast, GoT measures the perceptual dissimilarity of texture between two neighboring windows at each point in a seismic image along time or depth, and crossline directions, respectively. The GoT can effectively detect subtle variations characterized by changes in the texture of seismic data even in the absence of strong seismic reflections. We propose an interpreter-assisted workflow based on an attribute map obtained using either PC or GoT for computational seismic interpretation with an application to subsurface structures delineation within migrated seismic volumes. Experimental results show the effectiveness of PC and GoT for salt dome delineation on the SEAM dataset.
Introduction

Salt formations beneath the Earth’s surface are impermeable and form stratigraphic traps for petroleum and gas reservoirs. Furthermore, geomodeling and exploration studies require accurate delineation of salt bodies. Experienced geophysicists interpret the migrated data by observing the intensity and texture variations of seismic traces near different structures. The modern wide-azimuth and high-density seismic acquisitions have aided seismic interpreters by yielding seismic data with higher quality and better resolution. However, these techniques have resulted in the striking growth of acquired seismic data, which in turn are causing manual interpretation extremely time consuming and labor intensive. Therefore, there is an increased interest among researchers to automate the process of seismic interpretation. Over the last few decades, researchers have proposed several methods for salt dome delineation, which include edge-based detection methods by Zhou et al. (2007), Aqrawi et al. (2011), and Amin and Deriche (2015b), texture-based methods by Berthelot et al. (2013), Hegazy and AlRegib (2014), Shafiq et al. (2015b), Wang et al. (2015), and Shafiq et al. (2016b), active-contour- and level-set-based methods by Haukas et al. (2013) and Shafiq et al. (2015a), saliency-based methods by Drissi et al. (2008) and Shafiq et al. (2016a), machine-learning-based methods by Guillen et al. (2015), Qi et al. (2015), and Amin and Deriche (2015a), and other different image processing techniques by Lomask et al. (2004), Lomask et al. (2007), Halpert et al. (2009), and Wu (2016).

Phase Congruency (PC) originally proposed by Morrone et al. (1986) and modified by Kovesi (1999) is an edge detection approach based on the observation that the pixels along edges have Fourier components that are maximally in phase. PC varies between 0 and 1 corresponding to no and perfect phase congruency, respectively. PC is a dimensionless quantity that is not affected by the changes in image illumination and contrast, thereby making it practicable for images with dominating and inconspicuous edges. In seismic interpretation, Russell et al. (2010) and Kovesi et al. (2012) showed the efficacy of PC by detecting seismic discontinuities and velocity anomalies in migrated seismic volumes, respectively. Shafiq et al. (2017) applied PC for segmenting geophysical images that have chaotic structures and varying textures such as salt domes and showed its efficacy on seismic dataset from the North Sea, F3 block. In contrast, Gradient of Texture (GoT), a recently proposed method by Shafiq et al. (2016b), is a texture-based method, which defines the perceptual dissimilarity of the texture between two neighboring cubes that share a square face centered around each voxel in a migrated 3D volume. The GoT is computed in the spatial domain, whereas the texture dissimilarity function, which is calculated along time, crossline, and inline directions of given seismic volume $V$ is calculated in frequency domain. Shafiq et al. (2016b) showed the efficacy of GoT by segmenting salt domes from a real dataset acquired from the Netherlands F3 block in the North Sea.

In this paper, we present an approach for salt dome delineation based on different seismic attributes such as phase congruency and GoT. The proposed workflow leads to improved salt dome delineation by accurately and efficiently detecting the presence of strong and weak seismic reflections. The experimental results on the SEAM dataset (Fehler and Keliher, 2011) show the effectiveness of the proposed workflow for salt dome delineation.

Proposed Workflow

We propose an interpreter-assisted workflow for the computational seismic interpretation of salt domes as shown in Figure 1. Given a 3D seismic volume $V$, we apply pre-processing operations such as noise removal and image enhancement to yield a 3D seismic volume, $V_p$, for better feature detection. We then compute the attribute map (PC or GoT), which highlights the salt-dome edges and different geological features in a seismic image. In the next step, we determine an adaptive threshold $T_h$ using Otsu’s method to obtain a binary map of highlighted salt-dome boundaries, $B$, in which the white regions highlight the salt-dome boundaries. Next, we apply morphological processing operations, if required, to close the salt body and disconnect the noisy and non-salt regions, which have either low congruency in phase or low texture dissimilarity. To get rid of noise and detect a salt body $S$ from the binary map $B$, we apply a region growing method by manually selecting an initial seed point, $p_s$, and growing it pixelwise until it hits the salt-dome boundary. The region growing method yields a binary map of the salt body, $S$, which...
Experimental Results

To show the efficacy of the proposed workflow, the results of salt dome delineation on different seismic inline sections from the SEAM dataset (Fehler and Keliher, 2011), which contains a challenging salt-dome structure, are shown in Figure 2. The results of salt dome delineation obtained using PC attribute (Kovesi, 1999) are shown in Figure 2a-c, whereas the results of GoT (Shafiq et al., 2016b), are shown in Figure 2d-f. PC yields very good delineation even in the absence of strong seismic reflection as observed in the bottom left sides and the right sides of Figure 2. Similarly, GoT also yields good delineation results. However, GoT digresses from the observed salt-dome boundary in the absence of strong texture contrast. The careful examination of the results show that there are very minute differences in salt dome delineation obtained by PC and GoT. However, these areas can be interactively edited by the seismic interpreters to yield accurate results for the salt dome delineation. Finally, the delineation time required per slice by PC is 1.60 seconds as opposed to 84.75 seconds required by GoT. Subjective evaluation shows that the PC yields better results for salt dome delineation and is also computationally inexpensive as compared to the GoT.

Conclusions

In this paper, we have proposed a workflow for delineating salt domes within migrated seismic volumes using an edge-based (PC) and a texture-based (GoT) attribute. Each attribute yields a feature map, which is adaptively thresholded to produce a binary map. A software tool interactively guided by an interpreter and the region growing method are then used to accurately detect the salt bodies within seismic volumes. Experimental results on the SEAM dataset show the effectiveness of edge- and texture-based attribute maps for salt dome delineation. The proposed workflow is suitable for segmenting seismic volumes having weak seismic reflections, varying texture, illumination, and contrast. The workflow based on the PC map is computationally inexpensive and is expected to not only reduce the time for seismic interpretation but also become a handy tool in the interpreter’s toolbox for delineating geological structures.

Acknowledgements

This work is supported by the Center for Energy and Geo Processing (CeGP) at Georgia Tech and King Fahd University of Petroleum and Minerals.

References

Figure 2: The results of salt dome delineation using phase congruency (PC) and gradient of texture (GoT). Left column shows the results of PC, whereas right column shows the results of GoT.


