THE ROLE OF PERCEPTUAL TEXTURE DISSIMILARITY IN AUTOMATING SEISMIC DATA INTERPRETATION

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OUTLINE

• Background & Motivation
• Proposed Salt-Dome Detection Method
  – Gradient of Texture (GoT)
  – Thresholding & Post-processing
• Dissimilarity Measures
• Experimental Results
• Conclusion
MIGRATED DATA & SEISMIC INTERPRETATION

• Migrated data are acquired from reflected seismic waves

• Seismic interpretation is the extraction of geologic information from seismic data

http://www.oilinuganda.org/features/environment/uganda-pioneers-3d-seismic-surveys.html
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• Migrated data are acquired from reflected seismic waves

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http://tle.geoscienceworld.org/content/21/11/1118.extract
https://opendtect.org/osr/pmwiki.php/Main/NetherlandsOffshoreF3BlockComplete4GB
COMPUTER-AIDED INTERPRETATION

• Manual interpretation is time consuming and label intensive

• Image processing, computer vision, and machine learning techniques have been involved in seismic interpretation

• The interpretation of salt domes remains a challenging problem
### CONVENTIONAL METHODS FOR SALT-DOME INTERPRETATION

<table>
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<tr>
<th>Methods</th>
<th>Remarks</th>
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<td>Edge Detection</td>
<td>Sensitive to local discontinuities</td>
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<td>Graph-based Image Segmentation</td>
<td>Computationally less efficient</td>
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<td>Active Contour Model</td>
<td>Accuracy depends on the initial contour</td>
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<td>Multiple texture attributes</td>
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PROPOSED SALT DOME DETECTION METHOD

Seismic Sections

Compute “gradient of texture” (GoT)

Thresholding

Grow Region

Morph Operation

Initial Point Selection

Post-processing

Detected Salt Body
GRADIENT OF TEXTURE (GOT)

• Human perception is sensitive to texture changes

• Got describes the texture dissimilarity between two neighboring square windows, denoted as: \( d(W_{x-}, W_{x+}) \)

• Higher Got -> point on texture boundary
  Lower Got -> point inside the texture
Human perception is sensitive to texture changes.

GoT describes the texture dissimilarity between two neighboring square windows, denoted as: $d(W_{x-}, W_{x+})$

- Higher GoT -> point on texture boundary
- Lower GoT -> point inside the texture
MULTI-SCALE AND DIRECTIONAL COMPONENTS OF GOT

• Compare the dissimilarity of windows with various sizes
• Detect salt-dome boundary in any direction

• GoT:
\[
G_x[i, j] = \sum_{n=1}^{N} w_n \cdot d \left( W^i,j_{n,x-}, W^i,j_{n,x+} \right),
\]
\[
G_y[i, j] = \sum_{n=1}^{N} w_n \cdot d \left( W^i,j_{n,y-}, W^i,j_{n,y+} \right),
\]
\[
G[i, j] = \left( G_x^2[i, j] + G_y^2[i, j] \right)^{\frac{1}{2}},
\]

\( N \) : number of sizes

\( w_n \) : inversely proportional to \( n \)
THRESHOLDING AND POST-PROCESSING

• Hard Thresholding to highlight likely salt body
• Region growing and morphological operation remove noisy regions and smooth salt-dome boundary.

(a). Normalized GoT Attribute
(b). After thresholding
(c). After region growing
(d). After morphological operation
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DISSIMILARITY MEASURES USING FEATURE VECTORS

• $\mathbf{F}_-$ and $\mathbf{F}_+$ represent the feature vectors of $\mathbf{W}_+$ and $\mathbf{W}_-$.

• Dissimilarity measure: $d(\mathbf{W}_-, \mathbf{W}_+) = \| \mathbf{F}_- - \mathbf{F}_+ \|$

(1). Using intensity and gradient statistics:
   - Intensity-based features: mean, standard deviation, and skewness
   - Gradient-based features: mean, standard deviation, and entropy

(2). Using singular values of $\mathbf{W}_+$ and $\mathbf{W}_-$.
MEASURE BASED ON FOURIER TRANSFORM

(3). Using Fourier coefficients:

\[ d(W_-, W_+) = E \left\{ \| \mathcal{F} \{ W_- \} - \mathcal{F} \{ W_+ \} \| \right\} \]

(4). Using error spectrum chaos \(^1\): consistent with human perception

\[ d(W_-, W_+) = M + \alpha P, \]

\[ M = E \left\{ \| \mathcal{F} \{ \mathcal{F} \{ \nabla \{ |W_- - W_+| \} \} \} \| \right\}, \]

\[ P = E \left\{ \| \mathcal{F} \{ \angle \mathcal{F} \{ |W_- - W_+| \} \} \| \right\}, \]

PROPOSED MEASURE BASED ON ERROR MAGNITUDE SPECTRUM CHAOS

• This measure is inspired by the previous measure

• Dropping the phase: reduces the sensitivity to shape
  Dropping the gradient: improves computational efficiency

• Dissimilarity measure:

\[ d(W_-, W_+) = E \left\{ \mathcal{F} \left\{ \mathcal{F} \left\{ |W_- - W_+| \right\} \right\} \right\} \]
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EXPERIMENTAL SETUP

• Netherlands offshore F3 block with the inline number ranging from 389 to 409

• Compare five dissimilarity measures in the proposed salt-dome detection framework

• SalSIM index\[2\] derived from Frechet distance can be used to measure the similarity between detected boundaries and ground truth

### EXPERIMENTAL RESULTS

<table>
<thead>
<tr>
<th>Seismic Sections</th>
<th>Mag. Spect. Chaos</th>
<th>Spectrum Chaos</th>
<th>Fourier Coeff.</th>
<th>SVD</th>
<th>Basic Statistics</th>
</tr>
</thead>
<tbody>
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<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
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<th>0.9335</th>
<th>0.9214</th>
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<tbody>
<tr>
<td></td>
<td>Standard. Dev.</td>
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<td></td>
<td>GoT Time per Section (s)</td>
<td>14.5</td>
<td>438.8</td>
<td>14.8</td>
<td>24.2</td>
<td>1359.2</td>
</tr>
</tbody>
</table>
COMPARISON OF DETECTED SALT-DOME BOUNDARIES

(a). Basic Statistics, SalSIM=0.9362
(b). SVD, SalSIM=0.9293
(c). Fourier Coefficient, SalSIM=0.9405
(d). Spectrum Chaos (Mag. & phase), SalSIM=0.9389
(e). Mag. Spectrum Chaos, SalSIM=0.9471
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• In the proposed salt-dome detection framework, the perceptual measures are more consistent with human interpretation.

• Other perceptual measures in image/video quality assessment can be involved in seismic interpretation.

• We have extended the current framework to 3D for more accurate results.
RELATED WORK

• Salt-dome detection and tracking


• Fault detection and tracking


• Seismic structure retrieval


• Scene Labeling