OUTLINE

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Seismic data is obtained through the reflection of seismic waves from the earth’s subsurface. It contains important geological information which is used to identify a number of characteristics for the earth layers including;

- Faults, Horizons
- Structure, Structural Features
- Salt and other bodies
- Trap and rock properties
INTRODUCTION

(a) Fault Trap

(b) Salt Dome Trap

(c) Anticline Traps
Seismic Faults

- A Fault is a geological structure formed by a displacement between neighbouring tectonic plates.

- Faults seal the porous reservoir rocks and that leads to the formation of petroleum reservoirs.

- Seismic data sets typically contain a large number of faults at different scales.

- A good understanding of the fault positions is critical for the effective planning of drilling sites.

- This proves to be a challenging problem due to noise, imaging artefacts and large numbers of fault.
Seismic Faults

• Geological Fault Examples
Problem statement

- Due to high demand of oil, the area covered by seismic survey has grown and data can get up to hundreds of gigabyte in size.

- As a result of the complexity and size of the data an interpreter spend a reasonable amount of time in manual fault picking.

- An automatic fault detection and labelling will provide a faster and consistent interpretation workflow in the localization of fault lines.
Proposed Methodology

Input seismic section

- Coherence attribute
  - Coherence saliency map
- Curvature attribute
  - Curvature saliency map
- Dip attribute
  - Dip saliency map
- Gradient attribute
  - Gradient saliency map

Map weighting
- Combine saliency map
- Fault Highlighting
- Fault labelling
Literature review

- Hough Transform
- Ant colony algorithm
- Directional filtering
- Colour transformation
- Active contour
Seismic attribute

(a) time slice (b) coherence slice (Gersztenkorn et al., 1999)
Attribute Used

- Input seismic section
- Coherence attribute
  - Curvature attribute
  - Dip attribute
  - Gradient attribute
Variance based coherence attributes

Variance based coherence attribute

Coherency enhances abrupt changes in waveform that indicates fault and fractures in seismic sections. The variance based coherence is given as:

\[ c_v(x, y) = 1 - \frac{\sum_{j=-r}^{r} \left( \sum_{i=-r}^{r} s(x+i, y+j) \right)^2}{(2r+1) \sum_{i=-r}^{r} \sum_{j=-r}^{r} s(x+i, y+j)^2} \]

\( s(x, y) \) is the intensity of the seismic signal at point \((x, y)\).

\( x \) and \( y \) represent the coordinates on cross line and depth direction respectively.

\((2r+1)\) is the size of the analysis window.
Most Negative Curvature

- Most Negative Curvature attribute
  - Curvature attribute enhance property such as fault, fractures, and folds. Using grid cell approach the calculation of the coefficients reduce to a series of arithmetic expression following expression

  \[
  Z(x, y) = ax^2 + by^2 + cxy + dx + ey + f
  \]

  \[
  K_- = (a + b) - \sqrt{(a + b)^2 + c^2}
  \]

  \(a, b, c, d, e,\) and \(f\) are the coefficient of the equation 

  \(K_-\) is the most negative curvature

  \(x\) is the cross line and \(y\) is the depth direction
The dip attribute can highlight subtle faults that have throes. To calculate dip, we first calculate the instantaneous wave number in the cross line \((x)\) and depth \((y)\) direction.

\[
K_x(x, y) = \frac{u \frac{du^H}{dx} - u^H \frac{du}{dx}}{(u)^2 + (u^H)^2}
\]

\[
K_y(x, y) = \frac{u \frac{du^H}{dy} - u^H \frac{du}{dy}}{(u)^2 + (u^H)^2}
\]

\(\theta\) is the dip angle.

\(u\) is the seismic input.

\(H\) is the Hilbert transform.
Gradient Attribute

Gradient attribute

The gradient attributes is important as it highlight the edges in both cross line and depth direction. The edges in the cross line direction is usually associated with fault.

\[
\frac{du(x, y)}{dx} = \frac{u(x + \Delta x, y) - u(x, y)}{\Delta x}
\]

Where \( u \) is the input seismic section.
Different Attributes

: (a) variance-based coherence (b) curvature (c) dip (d) gradient on #inline256
Saliency

- Applications of saliency map
- Texture discrimination
- Object detection
- Object tracking
- Object segmentation
- Image retargeting

(a) a scene of a bicycle (b) overlaid saliency map (Yang et al., 2013)

(a) scene of a basket (b) overlaid saliency map (Harel et al., 2006)
Our saliency model used region covariance matrices of simple features for saliency estimation. The steps involve are as follows:

1. **Get the attribute image**
2. **Extract feature to form feature vector**
3. **Decompose the feature vector into patches**
4. **Compute the covariance matrix of each patch**
5. **Compute the neighbouring distance**
6. **Estimate the saliency**
Saliency Estimation

The saliency map is computed for each seismic attributes and combined to form a consolidated saliency map, which is given as:

$$S_c(R_i) = w_1S_{wc}(R_i) + w_2S_{cv}(R_i) + w_3S_{dp}(R_i) + w_4S_{gd}(R_i)$$

- $S_c(R_i)$ is the saliency map of the combined map.
- $S_{wc}(R_i)$ is the saliency map of the variance base coherence.
- $S_{cv}(R_i)$ is the saliency map of the curvature.
- $S_{dp}(R_i)$ is the saliency map of the dip.
- $S_{gd}(R_i)$ is the saliency map of the gradient.

$w_1, w_2, w_3, w_4$ are the respective weights of the individual attributes.
# Experimental set up

<table>
<thead>
<tr>
<th>Parameters</th>
<th>symbols</th>
<th>values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of blocks</td>
<td>$k$</td>
<td>[16, 32, 64]</td>
</tr>
<tr>
<td>Weights of saliency maps</td>
<td>$w_1$, $w_2$, $w_3$, and $w_4$</td>
<td>[0.1, 1, 0.1, 1]</td>
</tr>
<tr>
<td>Radius</td>
<td>$r$</td>
<td>3</td>
</tr>
<tr>
<td>Number of similar regions</td>
<td>$m$</td>
<td>[1/10 of the surrounding region]</td>
</tr>
<tr>
<td>Dimension</td>
<td>$d$</td>
<td>7</td>
</tr>
<tr>
<td>Standard deviation</td>
<td></td>
<td>0.02*512</td>
</tr>
</tbody>
</table>
Saliency Results

Saliency map of (a) coherence (b) curvature (c) Dip (d) gradient

Combined saliency map of all the attributes
Saliency Results

(a) inline # 256  (b) overlaid saliency map
Saliency Results

(a) inline # 249  (b) overlaid saliency map
Fault Labelling

- To label faults, the following steps were performed.

1. Fault enhancement
2. Binary thresholding
3. Optimization
4. Line fitting
After removing the false feature, the remaining points are connected successively to form the initial fault line. The position of a point $i$ in the labelled line $P_c$ can be denoted as:

$$P_c(i) = (x_c(i), y_c(i)) \quad i=1,2,3,$$

line connection of (a) inline # 256 (b) inline # 272
Numerical Optimization

Optimization using both the coherence and curvature map (a) inline # 256 (b) inline # 272
Labelled Fault and Ground Truth

- Comparing the labelled points with the ground truth (manually labelled fault points).

(a) ground truth (red) of inline # 256, fault line detected using proposed method
(b) ground truth (red) of inline # 272, fault line detected using proposed method
Performance Evaluation

• We applied Frechet distanced-based similarity index (SalSIM) proposed by Wang et al. (2015). For a number of segments $Nd$, a sequence of distances $d=\{d_i\}, i=1,2,\ldots,Nd$ is obtained. The SalSIM is given as

$$SalSIM = e^{-\alpha (\mu_d + \sigma_d)} e^{-\beta d_{\text{max}}}$$

$\mu_d$ and $\sigma_d$ are the mean and standard deviation of $d$ used as local parameter

$d_{\text{max}}$ is the Frechet distance of the entire boundary used as global parameter

$\alpha$ and $\beta$ are the empirically determined normalization factors.
The proposed algorithm outperforms the method using Hough transform by Wang et al. (2014).

The SalSIM indices of inline # 256 to inline # 274 of the proposed approach (green) and the SalSIM indices of inline # 256 to inline # 274 of the method by Wang et al (2014)
Conclusion

- The proposed system for automated fault highlighting and detection was developed and tested on a series of inline extraction from 3D seismic volume obtained from Netherland offshore F3 block North sea.

- We showed, for the first time, the high potential of employing saliency maps for fault highlighting and visualization.

- The proposed fault labelling technique is computationally efficient and provides very inputs to the interpreters.