Terrain Classification for Seismic Acquisition Surveys using Remote Sensing Methods
Context

- Background
- Objective
- Datasets/Processing
- RS workflow for terrain classification
- Limitations/ challenges
- Seismic productivity map
- Results

Machine Learning
Lekhwair example
Results
Conclusion
Background

- Understanding surface topography is vital for seismic survey planning
- Surface roughness affects the speed of seismic acquisition
- Seismic acquisition is a costly business utilizing critical labor assets
- Significant amounts of driving and scouting
- Involves high HSE exposure
- Remote areas
- Time inefficient
- Extensive equipment required
Objective

- Use remote sensing technology to improve and automate the terrain classification of seismic surveys in advance of the acquisition

- Capture the following terrain classification types:
  - **Flat**: terrain and undulate gravel plain - accessible to drive with a 4WD vehicle with minimal detours
  - **Rough**: terrain containing broken grounds, scarps, jebels and wadis – drive is restricted with a 4WD vehicle may require detouring
  - **Facilities**: terrain containing frequent occurring surface such as flowlines, wellhead and other oilfield assets and infrastructure – require significant detours
  - **Sand Dunes**: all types of sand dunes considered to be serious impediments
  - **Sabkha**: Salt flat – soft to be graded
Surveyed Area

- Nimr B ~ 1997 sqkm
- Nimr C ~ 2687 sqkm
Datasets

- **Sentinal 1 – Rada imaging (10m)** – Polar-orbiting, all weather, day/night radar imaging mission

- **DSM (2m)** – Generated from NSA high resolution aerial imaging

- **Aerial Photo (0.5m)** – NSA high resolution imaging
Data Pre-Processing

Radar Derived Roughness Index

- Multi-temporal Images
- Orbit Information
- Thermal Noise Removal
- Calibration
- Co-registration
- Stack Average
- Terrain Correction
- Backscattering Threshold Classes
- Roughness Index

DSM Derived Slope/Roughness

- Digital Surface Model DSM-2m
- DSM To Degree Slope & Roughness
- Slope & Roughness Classes

Classification of Optical Images

Helped to classify different land cover within AOI
Workflow

High-Res / MS Medium -Res

DSM Elevation

Radar Imagery

Ground Truth / Field Verification

Calibration

Land Cover Classes

Slope/Rough Classes (Degrees)

Roughness Classes

Weighted Overlay

Final Risk Map
**Datasets and Processing**

**DSM**

**Slope**

**Roughness**

*Slope* is the angle of inclination to the horizontal
*Roughness* is the difference of a central pixel and its surrounding cell
Radar Concept

- Rougher surface = higher backscatter (bright pixel)
- Smooth surface = lower backscatter (dark pixel)
Radar and Ground Truthing

Sentinel 1 VH C band

Point 23

Point 8

Point 5
## Ground Truthing / Field Verification

<table>
<thead>
<tr>
<th>Name</th>
<th>Easting</th>
<th>Northing</th>
<th>Description</th>
<th>CSR Comments</th>
<th>TCF</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 386829</td>
<td>2159820</td>
<td></td>
<td>Rough top of a hill/ridge</td>
<td></td>
<td></td>
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<tr>
<td>2 385052</td>
<td>2159830</td>
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<td>Low Radar backscatter- flat/smooth?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 386451</td>
<td>2159130</td>
<td></td>
<td>High Radar backscatter- rocks?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 386661</td>
<td>2159770</td>
<td></td>
<td>Flat down the hill/ridge</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 391122</td>
<td>2079270</td>
<td></td>
<td>High radar backscatter near the wadi</td>
<td>Mostly flat gravel with some undulation and loose/broken rocks on the surface.</td>
<td></td>
</tr>
<tr>
<td>6 383333</td>
<td>2119350</td>
<td></td>
<td>High radar backscatter-flat/gravel?</td>
<td>Flat, featureless gravel.</td>
<td>Flat</td>
</tr>
<tr>
<td>7 379464</td>
<td>2080770</td>
<td></td>
<td>High radar backscatter-flat/gravel?</td>
<td>Undulating gravel, bumpy in places.</td>
<td>Flat/Rough</td>
</tr>
<tr>
<td>8 380955</td>
<td>2078240</td>
<td></td>
<td>High radar backscatter near the wadi</td>
<td>Flat gravel with a lot of loose/broken rocks on the surface. No elevation change of note with adjacent wadi.</td>
<td></td>
</tr>
<tr>
<td>9 368454</td>
<td>2071840</td>
<td></td>
<td>High radar backscatter-flat/gravel?</td>
<td>Mostly undulating gravel with some rougher/uneven areas.</td>
<td>Flat</td>
</tr>
<tr>
<td>10 393883</td>
<td>2070170</td>
<td></td>
<td>High radar backscatter-flat/gravel?</td>
<td>Undulating gravel with some broken up terrain and small/craggy drop-offs.</td>
<td>Flat/Rough</td>
</tr>
<tr>
<td>11 396548</td>
<td>2080710</td>
<td></td>
<td>High radar backscatter- rocky hill?</td>
<td>Rocky hill with an undulating, broken up plateau.</td>
<td>Rough</td>
</tr>
<tr>
<td>12 371276</td>
<td>216800</td>
<td></td>
<td>Low Radar backscatter-flat</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13 366849</td>
<td>2166290</td>
<td></td>
<td>High radar - mid slope</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14 383320</td>
<td>2111440</td>
<td></td>
<td>High radar - mid slope</td>
<td></td>
<td></td>
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<tr>
<td>15 383320</td>
<td>2131460</td>
<td></td>
<td>High radar - low slope</td>
<td>Rough plateau, low slopes.</td>
<td>Rough</td>
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<tr>
<td>16 382702</td>
<td>2132990</td>
<td></td>
<td>Low radar - low slope-flat</td>
<td>Flat, sandy and featureless wadi. NO slope.</td>
<td>Flat</td>
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<tr>
<td>17 386165</td>
<td>2138920</td>
<td></td>
<td>Mid radar - low slope can you drive over it?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18 388444</td>
<td>2073790</td>
<td></td>
<td>High radar - flat/gravel</td>
<td>Flat gravel.</td>
<td>Flat</td>
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<tr>
<td>19 378381</td>
<td>2035930</td>
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<td>High radar - flat/gravel</td>
<td>Flat gravel.</td>
<td>Flat</td>
</tr>
<tr>
<td>20 374340</td>
<td>2011350</td>
<td></td>
<td>High radar - flat/gravel</td>
<td>Flat.</td>
<td>Flat</td>
</tr>
<tr>
<td>21 375436</td>
<td>2010360</td>
<td></td>
<td>High radar - flat/gravel</td>
<td>Flat gravel with rocky surface outcrops.</td>
<td>Flat</td>
</tr>
<tr>
<td>22 369246</td>
<td>2015290</td>
<td></td>
<td>Is this wadi accessible?</td>
<td>Flat sandy/gravel wadi.</td>
<td>Flat</td>
</tr>
<tr>
<td>23 389967</td>
<td>2075760</td>
<td></td>
<td>Is this wadi accessible?</td>
<td>Flat.</td>
<td>Flat</td>
</tr>
<tr>
<td>24 386057</td>
<td>2116840</td>
<td></td>
<td>Is this wadi accessible?</td>
<td>Flat.</td>
<td>Flat</td>
</tr>
<tr>
<td>25 372907</td>
<td>2103080</td>
<td></td>
<td>Is this wadi accessible?</td>
<td>Flat.</td>
<td>Flat</td>
</tr>
<tr>
<td>26 370691</td>
<td>2167050</td>
<td></td>
<td>Mead radar- high slope at edge of hill/diff</td>
<td>Flat.</td>
<td>Flat</td>
</tr>
<tr>
<td>27 373034</td>
<td>2032640</td>
<td></td>
<td>High radar - low/mid slope</td>
<td>Ground is sandy and soft in places. Surface is rough, bumpy and difficult to drive through with a lot of vegetation.</td>
<td></td>
</tr>
<tr>
<td>CSR Points for Ground Truthing check:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>51 371492</td>
<td>2014920</td>
<td></td>
<td>Rocky, cut-up terrain adjacent to a jebel.</td>
<td>Rough.</td>
<td></td>
</tr>
<tr>
<td>53 372696</td>
<td>2014088</td>
<td></td>
<td>Gravel plain with exposed rock at surface.</td>
<td>Rough.</td>
<td></td>
</tr>
<tr>
<td>55 382346</td>
<td>2081398</td>
<td></td>
<td>Small, rocky wadi with low slopes.</td>
<td>Rough.</td>
<td></td>
</tr>
<tr>
<td>57 385846</td>
<td>2100796</td>
<td></td>
<td>Area of extensive earthworks and surface scarring/scrappings.</td>
<td>Rough.</td>
<td></td>
</tr>
</tbody>
</table>
## Calibration with Ground Truthing

### Attempt to remove gravel backscattering using field data

<table>
<thead>
<tr>
<th>Point number</th>
<th>Sentinel 1 VH (C band, 10m)</th>
<th>Sentinel 1 VV (C band, 10m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>-15.23</td>
<td>-11.50</td>
</tr>
<tr>
<td>8</td>
<td>-17.20</td>
<td>-7.03</td>
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<tr>
<td>6</td>
<td>-18.87</td>
<td>-12.50</td>
</tr>
<tr>
<td>9</td>
<td>-16.20</td>
<td>-10.97</td>
</tr>
<tr>
<td>10</td>
<td>-16.79</td>
<td>-10.50</td>
</tr>
<tr>
<td>7</td>
<td>-18.11</td>
<td>-10.18</td>
</tr>
<tr>
<td>18</td>
<td>-18.53</td>
<td>-10.01</td>
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<tr>
<td>19</td>
<td>-16.33</td>
<td>-11.44</td>
</tr>
<tr>
<td>20</td>
<td>-16.76</td>
<td>-10.86</td>
</tr>
<tr>
<td>21</td>
<td>-19.50</td>
<td>-11.94</td>
</tr>
<tr>
<td><strong>SD</strong></td>
<td><strong>1.35</strong></td>
<td><strong>1.502538962</strong></td>
</tr>
<tr>
<td><strong>MIN</strong></td>
<td><strong>-19.50</strong></td>
<td><strong>-12.50</strong></td>
</tr>
<tr>
<td><strong>MAX</strong></td>
<td><strong>-15.23</strong></td>
<td><strong>-7.03</strong></td>
</tr>
<tr>
<td><strong>MEAN</strong></td>
<td><strong>-17.35</strong></td>
<td><strong>-10.69</strong></td>
</tr>
</tbody>
</table>
Gravel Elimination by backscattering

Sentinal 1 VH

Sentinal 1 VV

- Smooth
- Gravel
- Rough
Risk Map Generation

DSM Roughness – 50%

Radar Roughness – 50%

Weighted Sum

Result
Field Cross-checking & feedback

• Field verification showed very good correlation with RS classification

• RS classification pick up areas of ridges, rough undulations and small hills very well

• Types of rough terrain not picked:
  - Wadis with clumpy vegetation
  - Excavated areas
Limitation / Challenges

- Mapping vegetation
Limitation / Challenges

- Mapping earthworks & scrapings
Seismic Productivity Forecast Maps

- Use terrain assessment & seismic acquisition production formula
- Create detailed forecast of productivity to assist in project planning and management

\[ CTM = \frac{3600}{(S+M)} \times 22 \times (N-X) \times TCF \times B \]

- Accurate production forecast in advance
- Highlight difficult terrain areas to implement mitigation for any reduced productivity that may arise
- Provides input to accurate budget for each project
### Productivity Calculation Nimr C

#### Remote Sensing Terrain Based Seismic Productivity Calculator

<table>
<thead>
<tr>
<th>Variables</th>
<th>Value</th>
<th>Unit</th>
<th>Comments</th>
<th>Project Source Points per Km²</th>
<th>VPs in each Terrain (Km² x (VPs/Km²))</th>
<th>Productivity N (number of days in each area)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S (Sweep Length)</td>
<td>9</td>
<td>Seconds</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M (Move up time for Vibrator)</td>
<td>18</td>
<td>seconds</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operation time per day in Hours (constant new)</td>
<td>22</td>
<td>Hours</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variables</th>
<th>Value</th>
<th>Unit</th>
<th>Comments</th>
<th>Input Area in Each Terrain based on Automated Terrain Classification (Km²)</th>
<th>VPs in each Terrain (Km² x (VPs/Km²))</th>
<th>Productivity N (number of days for a project/area)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCF (Flat)</td>
<td>0.85</td>
<td>Factor for that area</td>
<td>2578.4</td>
<td>2062794</td>
<td>68.94</td>
<td></td>
</tr>
<tr>
<td>TCF (Rough)</td>
<td>0.5</td>
<td>Factor for that area</td>
<td>1291.6</td>
<td>1034872</td>
<td>58.80</td>
<td></td>
</tr>
<tr>
<td>TCF (Facilities)</td>
<td>0.55</td>
<td>Factor for that area</td>
<td>206.2</td>
<td>217935</td>
<td>11.00</td>
<td></td>
</tr>
<tr>
<td>TCF (Sand Dunes)</td>
<td>0.6</td>
<td>Factor for that area</td>
<td>0.0</td>
<td>0</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>TCF (Soft Sabah)</td>
<td>0.6</td>
<td>Factor for that area</td>
<td>0.0</td>
<td>0</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Total Project Area (Km²)</td>
<td>4138.1</td>
<td>Total No. Days for a project/Area</td>
<td>138.74</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Flat 62%, rough 32%, facilities 6.4%
Field Cross-checking & feedback

• Field verification showed very good correlation with RS classification

• RS classification pick up areas of ridges, rough undulations and small hills very well

• Types of rough terrain not picked:
  - Wadis with clumpy vegetation
  - Excavated areas
Results

• 83% reduction driven and days spent in the field
• Enhanced HSE planning
• Optimization of resources
• Accurate prediction of deliverables to clients
• Improved budget accuracy and compliance
PDO Concession

- Entire block 6
Machine Learning

- Leverage machine learning solution for terrain classification to reduce exploration costs and HSE risk
- Process has potential for optimization

Known examples of buildings, roads, etc.

Train

Input data

Classify

Productivity map

Plan for seismic acquisition area and productivity

Facility Rough Flat Sand

Not automated
• Multi-spectral satellite imagery, radar imagery and DSM selected as input data sources for the model

Sentinel-2 optical
• 10m / 20m resolution
• 9 spectral bands

Buildings, roads, sand etc. have different chemical compositions, which reflects across bands

Sentinel-1 SAR
• 10m resolution
• C-band

Buildings and other structures standing on the ground produce bright spots on radar imagery

Derived from aerial photography
• 2m resolution
• Elevation and Slope

Elevation and slope are the main contributors to Roughness
• Ensemble of specialized classifiers is the most common approach to manage the label overlap and improve the overall model performance
Models provide valid classification on Lekhwair (1/2)
Models provide valid classification on Lekhwair (2/2)
## Results

- Item-wise performance assessment reflects better visual assessment; high overall performance with room for improvement for Gravel roads

<table>
<thead>
<tr>
<th>Label</th>
<th>Visual assessment</th>
<th>Recall / Precision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bitumen roads</td>
<td>Good</td>
<td>95% / 90%</td>
</tr>
<tr>
<td>Sand</td>
<td>Good</td>
<td>95% / 80%</td>
</tr>
<tr>
<td>Pits pads (cleared soil)</td>
<td>Good</td>
<td>90% / 88%</td>
</tr>
<tr>
<td>Buildings</td>
<td>Good</td>
<td>90% / 62%</td>
</tr>
<tr>
<td>Gravel roads</td>
<td>Good</td>
<td>85% / 72%</td>
</tr>
<tr>
<td>High slope</td>
<td>Good</td>
<td>N/A (rule-based)</td>
</tr>
</tbody>
</table>
Improvement of labels will improve the model performance

1. Use existing labels
2. (Re-)train on areas with the highest level of confidence in labels
3. Classify areas with low confidence in labels or without labels
4. Improve labels using classification results and include in train area
Example of gravel road labels improvement using classification results

Gravel road not captured in Test area at first

Classification on Test area

Gravel road labels corrected accordingly

Combining this with item-wise performance, Recall and Precision jumped from 73% / 27% to 85% / 72%
Conclusion

- The approach has been proved successful capturing the desired terrain types
- Improved project planning
- Give accurate production forecast
- Reduced cost
- Reduced time
- Improve HSE exposure
Thank you