QUANTITATIVE STRUCTURAL ANALYSIS OF FRACTURES USING DIGITAL OUTCROP MODELS

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INTRODUCTION

Digital Outcrop Model - DOM

~2000 Technological Advances Present

- Image-quality
- Data collection
- Processing
- Positional data
- Visualization

- Practicality
- Agility
- High positional accuracy
- High spatial resolution
- Improved image-quality

- Visualization and interpretation in the office
- Field data analysis complementation
- Improvement of dataset representativity

Challenge
- Tools and methodologies for interpretation of linear and planar features from DOMs
- Handle large data set

STUDY AIMS

- **Systematize** the manual and semi-automatic methods of plane extraction using tools available in the open-source CloudCompare (e.g., Compass and Facets).
INTRODUCTION

• Location of the Araripe Basin in Northeastern Brazil

• Intracontinental rift basin positioned between the Patos and Pernambuco shear zones (Brazilian/Pan-African orogeny)

• Two different DOMs in this work (ARN02 & ARN04)

• They are on the fault zone context and represent the Araripe’s Basin basement

Study area
**ARN02**

- Natural outcrop along a creek
- Approximately 35m long and 5m height
- Tilted metamorphic rocks
- Intensely fractured with breccia zones (see dashed lines)

**ARN04**

- Road pavement pit
- Approximately 45m long and 4m height
- Orthogneisses and amphibolites
- Intensely fractured (joints and faults), mostly perpendicular to the outcrop wall.
**Field Data Collection**

- ARN02 & ARN04

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**3D Model reconstruction**

- Photogrammetric models
- Structure from Motion (SfM) technique
- Spatial resolution 0.3 mm/pixel

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**DOMs analysis**

- Extract fracture patterns with CloudCompare
- Plugins:
  - Compass
  - Facets

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**METHODOLOGY**

- Photographs captured directly from the ground

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- GNSS RTK positioning system +
  - ground control points
- Positional errors smaller than 2 cm

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**Results & Interpretation**

Example of SfM Photogrammetry workflow

Javadnejad (2018)
FACETS PLUGIN ➔ PLANES EXTRACTION METHODOLOGY

- FACETS ➔ plugin within CloudCompare (Dewez et al. 2016)
- Perform automatic planar facet extraction
- Segmenting massive 3D point clouds into individual planar facets
- Calculate their dip and dip direction
- Report the extracted data in interactive stereograms

COMPASS PLUGIN ➔ PLANES EXTRACTION METHODOLOGY

• **COMPASS** ➔ plugin within CloudCompare (Thiele et al. 2017)
• Rapidly interpolate structural features between manually defined control points ➔ point cloud and raster datasets
• Tools for measuring surface orientations, lineations and true thicknesses
• Map Mode ➔ delineating geological units
• **Compass Mode** ➔ measuring orientations and thicknesses

Why is the point cloud manual clean-up an essential step before extracting the planar structures?
Reduce noise and point cloud size \(\rightarrow\) optimize processing

This step significantly increases the measurement accuracy (True planes \(\times\) False planes)
Facets Tool in the ARN02 area: EFFECTIVE

Outcrop wall orientation:
- bedding planes (So) (green): perpendicular → large area
- breccia zone (blue): fracture dip direction perpendicular and parallel

Many true planes extracted (almost all the outcrop) → Why?
- True planes are visible

Facets Tool in the ARN04 area: INEFFECTIVE

Outcrop wall orientation:
- fracture dip direction parallel

Few true planes extracted → Why?
- less visible planes exposed to calculate automatically.
- most of the fractures are exposed as lines (trace)

In cases like this (only line visible), manual planar extraction using the Compass tool is more effective.
RESULTS

Structural Analysis comparing the DOM measurements (Compass - manual planar extraction tool) and field measurements

- Fractures preferential orientation: N45-50°E
- Dip: variation along the structure
- The fractures measurements in this outcrop are part of a negative flower structure, typical of the shear zone, generated by strike-slip tectonic efforts.

Field Measurements (below the dotted line)
- 80 planes measurements
- 23 principal fractures

DOM Measurements (overall outcrop)
- 86 planes measurements
- 23 principal fractures (same structures that were identified in the field)
## FACETS vs. COMPASS

<table>
<thead>
<tr>
<th>FACETS</th>
<th>COMPASS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good tool for large scale surveys</td>
<td>Good tool for small scale surveys</td>
</tr>
<tr>
<td>Semi-automatic</td>
<td>Manual</td>
</tr>
<tr>
<td>Exporting data in .csv</td>
<td>Exporting data in .csv</td>
</tr>
<tr>
<td>Report the extracted data in interactive stereograms</td>
<td>• Don’t report interactive stereograms.</td>
</tr>
<tr>
<td></td>
<td>• Necessary export the data collection</td>
</tr>
<tr>
<td>• The planar facets extracted are easily separated in families and subfamilies sets (interactive)</td>
<td>No interactive data sets</td>
</tr>
<tr>
<td>• Spatial orientation similarity (azimuth).</td>
<td></td>
</tr>
<tr>
<td>Necessary a good plane exposed to be truly segmented using the tool</td>
<td>Identify planes (with few exposition) and lines using different compass mode tools</td>
</tr>
<tr>
<td>Tool advantages: user-friendly (practical, agile and accessible) and free access</td>
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<td>Tool disadvantage:</td>
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<tr>
<td>Semi-automatic extraction → Slow interpretation process because in this mode a detailed analysis by an expert is necessary to validate the quality and accuracy from the results</td>
<td>Manual extraction → analyst selects the best place to get the measurements.</td>
</tr>
</tbody>
</table>

Comparative table (Facets vs. Compass) according to the results obtained with these two study cases → ARN02 e ARN04
CONCLUSIONS

FACETS
- ARN04 → EFFECTIVE → 498 true planes → 62% data accuracy
- ARN02 → INEFFECTIVE → 37 true planes → 10.9% data accuracy

Why exist this accuracy difference?
Outcrop morphology difference
Visualization of the true planes in the point cloud

COMPASS
ARNO2 → EFFECTIVE → Comparison between DOM vs. Field measurements

Good tool to measure no visible planes

- The analyst must observe the outcrop wall orientation, as well as the orientation of the structures. These steps are essential to select the best tool to perform the structural analysis of fractures using digital outcrop model.

- Positional accuracy and visual quality are crucial for accurate quantitative interpretation of structural features using digital outcrop models, as well as a well-defined data processing routine and careful inspection of the results by an expert.

- The data obtained from this methodological approach will contribute to quantitative analyzes in structural geology based on robust datasets.
ACKNOWLEDGEMENTS

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