Automatic Analysis of Terrestrial Laser Data for Rock Mechanics

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Content

1. Introduction
2. Discontinuities: types and properties
3. Characterisation of the geometric properties of discontinuities
4. Assessment of 3D terrestrial laser scanning
5. Field data acquisition
6. Methods for analysing point cloud data
7. Extracting discontinuity planes with surface reconstruction
8. Extracting discontinuity planes with point cloud segmentation
9. Deriving discontinuity information
10. Conclusions
Introduction – problem definition

- Rock mass characterisation plays a very important role in the design of tunnels, mines, open excavations, slopes, foundations
- Rock mass = intact rock + fabric
- Fabric = system of discontinuities
- Conventional (manual) field survey of discontinuities in rock exposures:
  - Simple +
  - Effective +
  - Biased -
  - Inaccurate -
  - Limited -
  - Dangerous -
  - Labour-intensive -
Introduction - method

- Remote sensing offers logical alternative for conventional surveying of rock exposures, e.g.:  
  - Terrestrial 3D digital photogrammetry  
  - Terrestrial 3D laser scanning
- Objective of the research:  
  - Review conventional survey techniques  
  - Review 3D laser scanning  
  - Carry out field surveys  
  - Develop/adopt data processing techniques to derive discontinuity information
Discontinuities

Discontinuities are planes of weakness in the rock (low shear strength)

Discontinuities divide the rock mass in blocks that can move relative to each other

Discontinuities make a rock mass weaker (more discontinuities – smaller blocks – more options for movement – rock mass weaker)
Discontinuities sets

Discontinuities are in sets

Some sets contain few discontinuities per set while other may contain many thousands per cubic meter rock mass (depends on the geological history of the rock mass)
Discontinuities sets (2)

Measuring each discontinuity is often impossible:
- Simply too many
- Cannot be accessed (e.g. too high)
Discontinuities - types

- Bedding planes
- Joints
  - Cooling
  - Unloading or exfoliation
  - Tectonic
- Faults
- Shear zones
- Foliation
  - Cleavage
  - Schistocity
- Fractures
  - Man-made
  - Fractures through rock-bridges
Bedding planes...
Bedding planes
Joints
Cooling jointing
Exfoliation jointing
Discontinuities

sub-vertical jointing

bedding planes
Discontinuities - properties

- Geometrical properties:
  - Orientation,
  - Joint set spacing
  - Surface roughness,
  - Continuity or persistence
  - Aperture

- Non-geometrical properties:
  - Thickness and nature of infilling material,
  - Degree and amount of surface weathering
  - Bonding of discontinuity surfaces by cementation or mineralisation
  - Separation of discontinuity surfaces by karstification
Characterisation of the geometric properties of discontinuities

- **Orientation:**
  - Geological compass
  - Dip direction/dip angle (270/35)
- **Spacing:** measuring tape
  - Total spacing
  - Set spacing
  - Normal set spacing
- **Roughness:**
  - Contact methods
  - Non-contact methods
  - Observational methods
- **Persistence:**
  - Guestimate…
Characterisation of the geometric properties of discontinuities

- Conventional survey techniques of rock exposures:
  - Scanline survey
  - Cell mapping
  - Rapid face mapping
3D laser scanning - principles

- Emission and reflection of laser pulse – distance measurement
- Scanning geometry by changing azimuth and angle of laser beam
- Data output: 3D point cloud (x,y,z,intensity,R,G,B)
3D laser scanning of rock faces - operational issues (1)

- Horizontal and vertical sampling bias
  - Shadowing
  - Occlusion

[Diagram showing horizontal and vertical sampling bias with labels: Shadow, Planes parallel to laserbeam, Shadow]
3D laser scanning of rock faces - operational issues (2)

- Influence of vegetation
- Influence of “dynamic disturbances” in scene (cars, persons)
- Merging of multiple scans of larger scenes (e.g. open pit mines, tunnels)
3D laser scanning - operational issues (3)

• Point cloud have \((x,y,z)\) coordinates relative to scanner’s origin \((0,0,0)\)
• Registration
  • Use 4 targets (reflectors) in scene with known coordinates
  • Use orientation and level of scanner to orient point cloud to true north and horizontal
Case study – Spain

Rock exposure interbedded sand/siltstone, and shale/slate (Carboniferous Period; about 360-300 Ma old)

Optech Iliris (1st generation time-based) laser scanner (Long range < 1 km; Precision <20 mm; Slower < 12000 pnts/sec)

Field verification methods:
Scanline survey
Rapid face mapping: SSPC (Slope Stability Probability Classification)
Site 1 - Carboniferous Exposure
Result of scanline survey (stereo plot)

Discontinuity set 1

Discontinuity set 2

Discontinuity set 3
Methods for analysing point cloud data – character of point clouds

• 3D
• Data organisation
  • sequential
  • merged scenes: unorganised
  • no efficient spatial search possible
• Areas of sparse, absent data
• Noise, due to
  • limited precision
  • vegetation, dynamic disturbances
Methods for analysing point cloud data – processing techniques

A. Surface reconstruction
   • 2D gridding
   • 3D Delaunay triangulation
   • 3D implicit surface interpolation

B. Point cloud segmentation
   1. Structuring of the data
   2. Region-growing
   3. Evaluation of planarity using
      • Hough transform
      • Principal Component Analysis
      • (Total) Least Squares methods
Extracting discontinuity planes with surface reconstruction

Basic principle:

• reconstruct the original surface that the point cloud represents
• create a computer model of this reconstructed surface in the form of a mesh
• each mesh element (facet) contains geometric information
Surface reconstruction with an implicit representation (surface is represented by a function, e.g. partial derivatives)
Results for Site 1
Equal angle stereoplot (lower hemisphere)

Number of displayed poles: 457212

Rock surface area: 25.732 m²
Equal angle stereoplot (lower hemisphere)

Number of displayed poles: 457212

Rock surface area: 25,732 m²

Cluster characteristics

Cluster 1 (blue)
Mean N 075 / 03 106258
Fishers k: 6.141
R_mean 0.8372
n transport 0.1857

Cluster 2 (red)
Mean N 153 / 27 61125
Fishers k: 2.794
R_mean 0.6421
n transport 0.4235

Cluster 3 (yellow)
Mean N 024 / 37 64309
Fishers k: 16.72
R_mean 0.9402
n transport 0.1305

Cluster 4 (magenta)
Mean N 344 / 47 128156
Fishers k: 10.95
R_mean 0.9007
n transport 0.1242

Cluster 5 (cyan)
Mean N 053 / 18 97352
Fishers k: 19.83
R_mean 0.9406
n transport 0.1036
Reconstructed surface

discontinuities of same set have same colour
Surface reconstruction with 2D gridding

- With Software Split-Fx: http://www.spliteng.com/split-fx/
Results for Site 1
Extracting discontinuity planes with point cloud segmentation

- Basic principle
  1. Structuring of the data
     - using kd-tree structuring or
     - Delaunay triangulation
  2. Take a random seed point and find points around this seed that form a plane
  3. Region-growing from this seed plane
     - Using nearest neighbour search
  4. Evaluation of planarity using
     - Hough transform
     - Principal Component Analysis
     - (Total) Least Squares methods
  5. Repeat steps 3 and 4 until plane does not grow anymore
Results for Site 1
Deriving discontinuity information – orientation and discontinuity sets
Site 1 – Method 1 (surface reconstr)
Site 1 - Method 2 (2D gridding)
Site 1 - Method 3 (direct segment.)
Site 1 – Scanline survey results
Comparison

Surface reconstruction  2D gridding  Direct segment  Scanline
Deriving discontinuity information - spacing

- Normal set spacing can be derived after clustering into sets
- The plane equation of each individual plane of the set give distance to origin:
  \[ ax + by + cz + d = 0 \]
- Distances between subsequent planes give spacing
Discussion (1)

Scanline:

- Operator bias
- Only limited area of exposure is measured
- Not every discontinuity is measured – the operator decides based on a-priori knowledge which discontinuities are important enough to be included
Discussion (2)

Rapid face mapping:
• Operator bias
• Whole exposure
• Depends to some extent on operator expertise
Discussion (3)

Lidar scan:
• No operator bias
• Whole exposure
• Every discontinuity is measured
• Shadowing and occlusion
Discussion (4)

Different methods lead inherently to different results

Which is better: Manual or Lidar?

Lidar theoretically better (however, important but few discontinuities may be missed in-between many unimportant discontinuities)

Methods should be used both:
Rapid face mapping with Lidar is probably best and fast
Conclusions (1)

Laser scanning provides different information on rock masses mapping compared to conventional mapping:

- Visual Information
- Spatial Information
- Geometrical Information
- Physical Information
Conclusions (2)

- Allows interactive mapping in 3D virtual digital model
- High accuracy comparing to conventional (manual) methods
- Set up a 3D virtual database for retrieval evaluation
- Greatly improves the field mapping data quality
- Provide high quality of rock face mapping data to rock mechanic analysis and further numerical modeling
- Safe, fast, less biased
- Reach inaccessible areas, coverage of entire exposure possible

But:
- Control on results is required; hence combine with Rapid Face Mapping
References


