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Automated extraction and analysis of rock discontinuity characteristics from 3D point clouds

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A reliable characterization of fractured rock masses requires an exhaustive geometrical description of discontinuities, including orientation, spacing, and size. These are required to describe discontinuum rock mass structure, perform Discrete Fracture Network and DEM modelling, or provide input for rock mass classification or equivalent continuum estimate of rock mass properties. Although several advanced methodologies have been developed in the last decades, a complete characterization of discontinuity geometry in practice is still challenging, due to scale-dependent variability of fracture patterns and difficult accessibility to large outcrops. Recent advances in remote survey techniques, such as terrestrial laser scanning and digital photogrammetry, allow a fast and accurate acquisition of dense 3D point clouds, which promoted the development of several semi-automatic approaches to extract discontinuity features. Nevertheless, these often need user supervision on algorithm parameters which can be difficult to assess.

To overcome this problem, we developed an original Matlab tool, allowing fast, fully automatic extraction and analysis of discontinuity features with no requirements on point cloud accuracy, density and homogeneity. The tool consists of a set of algorithms which: (i) process raw 3D point clouds, (ii) automatically characterize discontinuity sets, (iii) identify individual discontinuity surfaces, and (iv) analyse their spacing and persistence. The tool operates in either a supervised or unsupervised mode, starting from an automatic preliminary exploration data analysis.

The identification and geometrical characterization of discontinuity features is divided in steps. First, coplanar surfaces are identified in the whole point cloud using K-Nearest Neighbor and Principal Component Analysis algorithms optimized on point cloud accuracy and specified typical facet size. Then, discontinuity set orientation is calculated using Kernel Density Estimation and principal vector similarity criteria. Poles to points are assigned to individual discontinuity objects using easy custom vector clustering and Jaccard distance approaches, and each object is segmented into planar clusters using an improved version of the DBSCAN algorithm. Modal set orientations are then recomputed by cluster-based orientation statistics to avoid the effects of biases related to cluster size and density heterogeneity of the point cloud. Finally, spacing values are measured between individual discontinuity clusters along scanlines parallel to modal pole vectors, whereas individual feature size (persistence) is measured using 3D convex hull bounding boxes. Spacing and size are provided both as raw population data and as summary statistics. The tool is optimized for parallel computing on 64bit systems, and a Graphic User Interface (GUI) has been developed to manage data processing, provide several outputs, including reclassified point clouds, tables, plots, derived fracture intensity parameters, and export to modelling software tools. We present test applications performed both on synthetic 3D data (simple 3D solids) and real case studies, validating the results with existing geomechanical datasets.