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Automated identification and characterisation of discontinuity sets in outcropping rock masses using 3D terrestrial laser scan survey techniques

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ABSTRACT: It is generally accepted that the identification and characterisation of discontinuities in discontinuous rock masses is one of the most important aspects in rock mass modelling. Traditional manual field survey methods for gathering discontinuity properties are biased, hazardous, difficult and time-consuming. This paper describes a computer approach, based on terrestrial laser scan data, which seems promising as an alternative survey technique. A terrestrial laser scanner can create rapidly, a highly accurate 3D point cloud models of any outcropping rock mass. The point cloud model can be converted into a virtual 3D surface using digital surface reconstruction. This paper describes a method using clustering algorithms that allow for automated identification and calculation of different discontinuity sets using these virtual rock surfaces. Not only is laser scanning a safer and faster surveying technique, it also provides a more accurate, precise and reliable basis for discontinuity identification and characterisation.

1 INTRODUCTION

Most engineering disciplines that deal with discontinuous rocks require a proper understanding of the character and behaviour of the rock mass under consideration. Rock mass description and characterisation is therefore an important first step in the design process. When dealing with discontinuous rock masses, the properties of discontinuities (joints, bedding planes and fractures) in the rock becomes of prime importance, since this will determine, to a large extent, the mechanical behaviour of the rock mass (Bieniawski, 1989).

2 TRADITIONAL FIELD SURVEY TECHNIQUES

The discontinuity properties can be determined in the field using standardised methods, such as scan line surveys or cell mapping (Priest and Hudson, 1981; Priest, 1993). Both systems have their respective advantages and disadvantages, but all manual field survey methods have three main disadvantages in common: large errors are often introduced due to sampling difficulties and human bias, safety risks are often considerable under steep and unstable slopes and direct access to rock faces is often difficult or impossible (Kemeny and Post, 2003).

3 TERRESTRIAL LASER SCANNING AS AN ALTERNATIVE TECHNIQUE

Glaser and Doolin (2000) already identified remote sensing as one of the primary goals for future research on in-situ rock mass characterisation. Considering the above-mentioned difficulties with traditional field survey methods, terrestrial 3D laser scanning techniques is considered by the authors of this paper as one of the most promising remote sensing technique that offers a sound basis for reliable rock mass characterisation.

A large advantage of 3D laser scanning is that it offers the possibility for real-time gathering of rock surface data without even having to get near the rock face. Rock surfaces can be scanned reliably from a large distance, depending on the type of scanner, even up to 250 metres. The survey yields a digital data set, which is essentially a dense "point cloud", where each point is represented by a coordinate in 3D space (X, Y and Z, relative to the scanner's position) and the reflected intensity (I) of the laser beam. Through the use of at least 4 reflectors in the scanned scene, whose absolute positions are known, the entire point cloud can be projected to a local (north-oriented) grid system, even in real-time.

One of the most important advantages of the laser scan method is however, that a very high point density or resolution, in the order of 1 cm, can be achieved. A new generation of laser scanners also yield for each point the passive colour (i.e.: Red, Green, and Blue reflection values) based on simultaneous acquisition of high-resolution digital images with a (11 Mpixel) digital camera (Riegl, 2004) – see Figure 1.

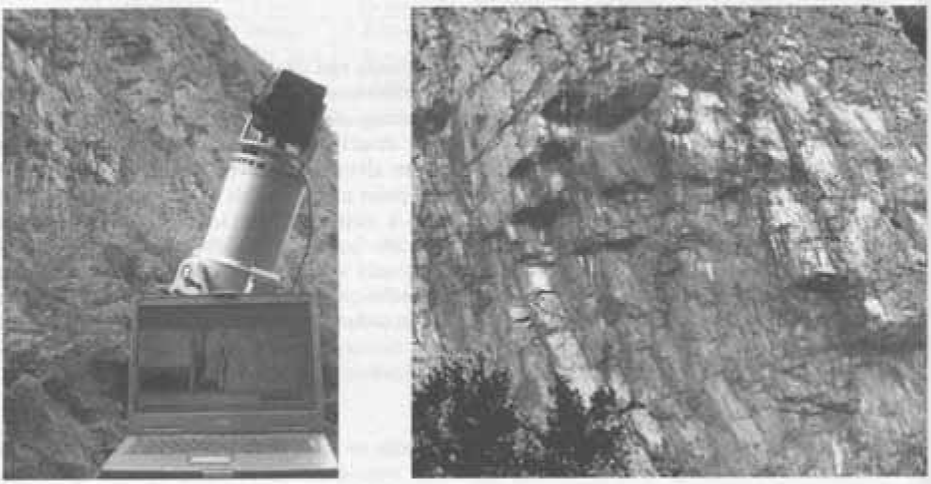

Figure 1. Laser scan survey set-up in the field, Dave (Belgium). The picture on the right shows a detail of the coloured 3D point cloud of the scanned rock face (note that this is <u>not</u> a photograph).

4 ROCK SURFACE RECONSTRUCTION

In order to analyse the character and shape of the scanned rock surfaces it is necessary to convert the irregularly distributed point data into surface information. Depending on the point cloud density, which is directly related to the laser's resolution and other parameters, the rock surface can be reconstructed with great detail by means of 2.5D gridding or 3D Delaunay triangulation. The reconstructed surface, which is now represented by facets or triangles, can be visualized using a variety of 3D visualization techniques (see Figure 2). From the reconstructed 3D surfaces, it is also possible to generate 2D profiles or contour lines for use in regular GIS or CAD packages.

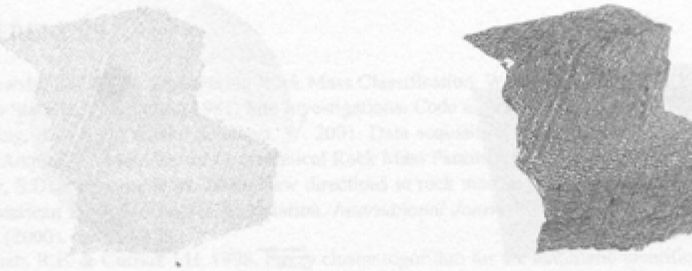

Figure 2. Surface reconstruction: from point cloud to 3D surface using Delaunay triangulation.

5 DISCONTINUITY ORIENTATION ANALYSIS

5.1 *Manual identification and outlining of joint sets*

Earlier applications have been developed that made use of (less accurate) photogrammetric principles (Fasching et al. 2001, Roberts & Poropat, 2000). In Poropat (2001) a more advanced approach is described, which allows for computer-based visualisation and indicative analysis of rock slopes, including discontinuity analysis using laser scan data. Currently, some of the software to operate the different available terrestrial laser scanners already allows real-time calculation of the orientations of individual discontinuity surfaces as well. An example is the latest version of RiSCAN Pro, the software to operate the Riegl scanner types (Riegl, 2004).

These methods do, however, still require manual identification and outlining of individual joint surfaces. Described below is an alternative approach, which will allow for an automated and unbiased identification and statistical calculation of all the visible joint sets.

5.2 *Automated identification of discontinuity sets using clustering techniques*

This approach (put forward by Slob et al. 2002) is based on the assumption that the geometry of the visible rock surface is for a large part determined by the discontinuity structures within the rock mass. In other words: every single facet of the virtually reconstructed 3D rock surface (consisting of many thousands to millions of facets) is in fact a small part of a discontinuity surface and should therefore be representing a certain discontinuity set. Following this rationale, by determining the direction cosines of each facet (the orientation) and subjecting subsequently these measurements to a clustering algorithm, identification of the different joint sets should be possible (see Figure 3). This approach will be less valid if the rock surface has been created by cutting through intact rock (using smooth-wall blasting for example), or if the rock surface has undergone extreme weathering.

For the clustering approach, the adjusted fuzzy k-means clustering method presented by Hammah and Curran (1998) is used. The disadvantage of this method is that a predefined number of clusters have to be entered first. Application of a vector quantisation method (Zhou and Maerz, 2002) or incorporation of a threshold value related to both the spherical distance and partition density can eliminate this. The orientation is the only input parameter for clustering at present. Other information (for example the intensity of the reflected laser beam or the colour information from the digital imagery) could be additional parameters to arrive at an improved clustering result.

Back-analysis of the clusters into XYZ-space will give individual point clouds of separate joints sets. By fitting planes to the point clouds representing the individual joint surfaces or patches, the joint spacing as well as its deviation with respect to the mean normal vector obtained for each cluster can be retrieved. A confidence level for the deviator angle needs to be established for this to define the allowable deviation in dip direction and dip angle from mean. In addition, measures of reliability need to be included.

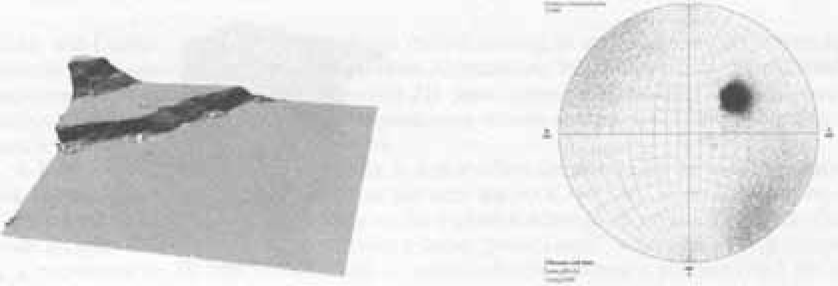

Figure 3. Example of a reconstructed surface, showing bedding planes, whose orientation can easily be recognised using a polar plot of all individual facets.

5.3 *Automated identification of discontinuity sets using facet merging techniques*

Another approach to identify and characterise discontinuity surfaces on the basis of laser scan data are put forward by Kemeny, Monte, Handy & Thiam (2003). These authors worked out a more direct approach to analyse the 3D virtual rock surfaces. This approach applies methods to combine the individual facets or triangles into larger merged joint surfaces (patches) based on certain threshold values. The orientation of the larger surfaces can subsequently be plotted in a stereonet and allows for rapid visual identification of joint sets and determination of the orientations. The advantage of this method is that irregular surfaces that create "noise" in the data, for example fractures through intact rock or weathered surfaces that do not seem to belong to a real discontinuity surface are not included in the analysis.

6 CONCLUSIONS AND RECOMMENDATIONS

The automation of the identification and characterisation of discontinuities in outcropping rock masses with the aid of 3D terrestrial laser scan survey techniques seems very promising. The application of fuzzy K-means clustering or vector quantisation results in an unbiased and statistically sound identification of discontinuity sets within an outcropping rock mass. Future research is directed towards the elimination of noise in the data and the errors in the surface reconstruction that results in incorrect discontinuity facets. Future research will also focus to compare and complement the laser-based data acquisition method with for example digital image analysis and geophysical GPR measurement, as well as the verification and comparison of results with traditional manual survey methods. Subsequently, research will be directed towards the automated computation of discontinuity spacing distributions and the determination of surface roughness characteristics of the identified discontinuity sets.

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