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Automatic extraction of discontinuity orientation from rock mass surface 3D point cloud

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ABSTRACT

This paper presents a new method for extracting discontinuity orientation automatically from rock mass surface 3D point cloud. The proposed method consists of four steps: (1) automatic grouping of discontinuity sets using an improved K-means clustering method, (2) discontinuity segmentation and optimization, (3) discontinuity plane fitting using Random Sample Consensus (RANSAC) method, and (4) coordinate transformation of discontinuity plane. The method is first validated by the point cloud of a small piece of a rock slope acquired by photogrammetry. The extracted discontinuity orientations are compared with measured ones in the field. Then it is applied to a publicly available LiDAR data of a road cut rock slope at Rockbench repository. The extracted discontinuity orientations are compared with the method proposed by Riquelme et al. (2014). The results show that the presented method is reliable and of high accuracy, and can meet the engineering needs.

1. Introduction

The orientations of discontinuities are of paramount importance for rock engineering studies because they affect rock mass stability and control fluid flow paths (Bieniawski, 1989). Discontinuity orientations are typically measured by a qualified field engineer using compass and inclinometer. This manual measurement process can be dangerous, time consuming, biased, error prone, and limited in its coverage (Poropat and Elmouttie, 2006). Therefore, photogrammetry is recommended to measure discontinuity by ISRM (1978). Recent advances in photogrammetry (Kemeny and Post, 2003; Roncella et al., 2005; Potsch et al., 2005; Haneberg, 2008; Sturzenegger and Stead, 2009; Li et al., 2016; Zhu et al., 2016) and LiDAR techniques (Lato et al., 2009, 2010; Otoo et al., 2011; Gigli and Casagli, 2011; Fisher et al., 2014; Riquelme et al., 2015) allow a quick and accurate characterization of rock mass discontinuities. The photogrammetry technique is capable of obtaining 3D point clouds from pairs of 2D images. LiDAR technology is another solution to obtain 3D point clouds. The pros and cons of both techniques have been discussed by many authors (Roncella et al., 2005; Potsch et al., 2005).

Extracting discontinuity orientations automatically from rock mass surface 3D point cloud (also called digital surface model, DSM) has attracted much research attention (e.g., Roncella et al., 2005; Lato et al., 2009; Slob, 2010; Otoo et al., 2011; Gigli and Casagli, 2011; Vöge et al., 2013; Riquelme et al., 2014). Usually, several scans are obtained from different points of view, and the resultant point clouds are subsequently aligned and merged to minimize directional bias and occlusion (Lato et al., 2009; García-Sellés et al., 2011). Automatic extraction of discontinuity orientation involves three questions: (1) determining the discontinuity sets automatically from DSM; (2) segmenting point clouds into disjoint sets of points, with each set corresponding to a discontinuity; and (3) calculating the orientation of each segmented discontinuity. Two major methods are adopted to explore the internal discontinuity structures in a DSM automatically or semi-automatically. The first method extracts discontinuities directly from raw 3D point cloud (Gigli and Casagli, 2011; Riquelme et al., 2014). It involves detecting planes by finding coplanar points in neighbors, and projecting normal vectors of detected planes to a stereonet to identify the number of sets. However, the dimension of the searching cube (or the number of neighbors) used to perform coplanar test are related to the undulating and roughness degree of rock mass surface. In addition, the number of sets is determined manually. The second method clusters a DSM into individual sets using fuzzy K-means clustering method, and construct discontinuity planes by joining connected facets within each set (Slob, 2010). However, the clustering result is sensitive to the selection of the initial centers, and the number of clusters needs to be specified before the algorithm is applied.

This paper presents a new method for extracting discontinuity orientations automatically from a 3D point cloud. The main contributions of the proposed method is twofold: (1) An improved K-means algorithm based on sample density and clustering

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validity index is proposed to group discontinuities automatically; and (2) Discontinuity segmentation is optimized by redistributing misclassified vertices and facets which are caused by undulating DSM surfaces.

This paper is organized as follows: an automatic discontinuity orientation extraction method is introduced in Section 2, the proposed method is applied to a road cut rock slope in Section 3, application of the method is discussed in Section 4, and some conclusions are drawn in Section 5.

2. Methodology

The method for discontinuity detection consists of four steps: (1) automatic grouping of discontinuity sets using an improved K-means clustering method; (2) discontinuity segmentation and optimization, in which facets and vertices are classified to planes, and misclassified facets and vertices resulting from curved and undulating DSM surfaces are redistributed; (3) discontinuity plane fitting using Random Sample Consensus (RANSAC) method (Fischler and Bolles, 1981; Torr and Murray, 1997; Roncella and Forlani, 2005; Ferrero et al., 2009); and (4) coordinate transformation of discontinuity plane, in which the normal vector of the discontinuity plane in the camera coordinate system is transformed into the desired world coordinate system.

2.1. Description of the datasets

Two datasets are used in this section. Case A consists of regular polygons scanned in laboratory conditions, which is available at www.3D-landslide.com/projects/discontinuity/ (Riquelme et al., 2014). Case B is a portion of a rock slope obtained by photogrammetry.

2.1.1. Case A

Two representative geometric shapes, a cube and a dodecahedron (Fig. 1a and b, respectively), were selected for analysis. Data were obtained using a 3D digitizer (Konica Minolta, Vivid 9i) through progressive rotation of the objects around a fixed platform axis and subsequent scanning (Riquelme et al., 2014).

The cube is represented using 60,488 points, and the dodecahedron is represented using 40,414 points. Both the cube and dodecahedron need to be triangulated into DSMs (digital surface models) before analysis. First, as the point cloud of the cube was too dense and its shape was relatively simple, the point cloud was resampled. Then, the Moving Least Squares method (Alexa et al., 2003) was used to reduce the noisy data generated by instrument errors, dust and dynamic disturbances (Slob, 2010). Finally, a

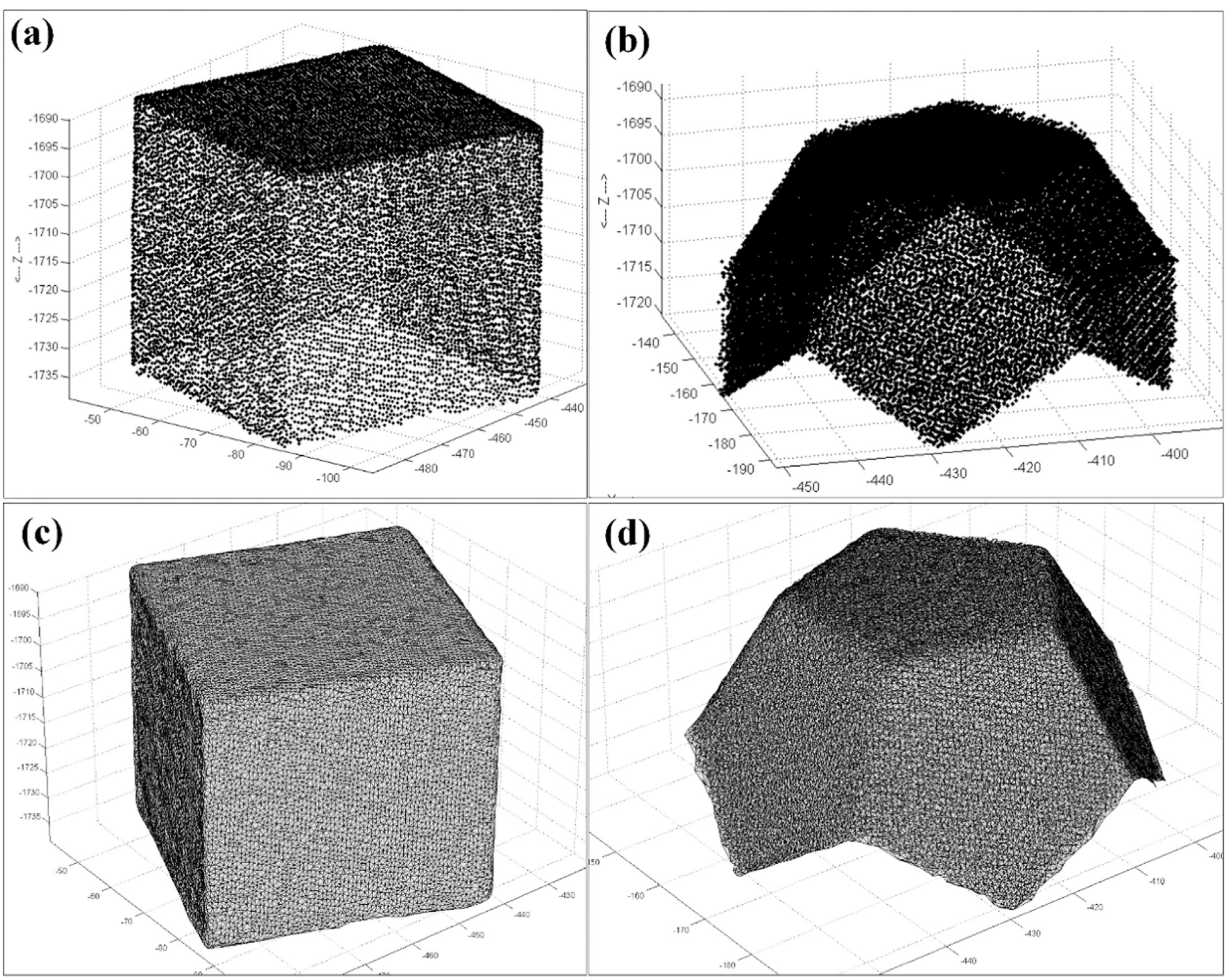

Fig. 1. (a) Raw data of a cube; (b) Raw data of a dodecahedron; (c) DSM of a cube after triangulation; (d) DSM of a dodecahedron after triangulation.