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Automated measurements of discontinuity geometric properties from a 3D-point cloud based on a modified region growing algorithm

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ABSTRACT

An approach was proposed to automatically measure the discontinuity geometric properties from a point cloud acquired using Light Detection and Ranging (LiDAR). The procedure primarily includes the following features: (Assali et al., 2016) Grid data from the point cloud was created to enhance computational efficiency for data processing and retrieval; (Barton & Choubey, 1977) A modified region growing (MRG) algorithm, which is characterized by more efficient grow criterion, was used to recognize discontinuities from the point cloud; (Cao et al., 2017) Four geometric properties from identified discontinuities were calculated based on analytic geometry; (Chen et al., 2016) Influence of threshold T on the identified results was investigated through sensitivity analysis, and threshold T was suggested to be less than the minimum normal difference among all joints and larger than 0°. Two cases (regular polyhedrons and a tunnel in the Rumei hydropower station) were taken as case studies to validate the developed approach, and calculation results have good agreement with real situations.

1. Introduction

Since rock discontinuities have a great impact on the mechanical behaviors of rock masses, an accurate measurement of the geometric properties of discontinuities is critical and fundamental in performing stability analysis for rock masses (Barton and Choubey, 1977). Several geometric parameters were suggested to quantitatively describe rock discontinuities, such as orientation, spacing, trace length, aperture, persistence, roughness, etc. (ISRM, 1978). A scanline or sampling window method is widely used to obtain these required parameters in a traditional geological survey in situ (Priest and Hudson, 1981; Zhang and Einstein, 1998), and they are characterized by direct access to the outcrop. The contact measurements have the following disadvantages: (Assali et al., 2016) it is impossible and dangerous to perform the surveys in inaccessible areas; (Barton & Choubey, 1977) generally, it is time and labor consuming to collect the data manually for detailed geological investigations or larger scale field surveys; (Cao et al., 2017) surveys are normally conducted on limited sectors of the outcrop, resulting in incomplete and rough geometric data.

Alternatively, several non-contact technologies are available for collecting the geometric parameters, such as Light Detection and Ranging (LiDAR) (Feng and Röshoff, 2004; Kemeny and Donovan, 2005; Fisher et al., 2014;), Ground Penetrating Radar (GPR) (Elkarmoty et al., 2017), Digital Photogrammetry (Sturzenegger and Stead, 2009; Assali et al., 2016), and the Borehole Digital Optical Televiewer (Wang et al., 2017a,b). LiDAR is a valuable tool for discontinuity mapping among these remote sensing technologies, and LiDAR applications in rock engineering are becoming more frequent as the geological community comes to realize LiDAR's strength for data collection. Meanwhile, these practices in recent years have proven the robustness and reliability of LiDAR for discontinuity mapping (Telling et al., 2017; Han et al., 2017).

In the LiDAR system, the discontinuity surface is represented by a high-resolution point cloud that includes XYZ coordinates. If necessary, intensity information captured by sensors and RGB values estimated using CCD cameras can be stored along with XYZ coordinates. The point cloud can be processed following two procedures, identification and extraction, to obtain the required geometrical parameters of discontinuities. The major issue that engineers have to address is to identify the points accurately from the point cloud that belong to the planar discontinuity, which is the foundation of extraction of geometric parameters. Explicitly, it is necessary to determine the points located on

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the discontinuities prior to measuring. However, recognizing the discontinuity manually by visual inspection is not always easy. Efficiency and accuracy greatly depend upon the skill level and background of engineers. Additionally, some details hidden in the point cloud tend to be ignored. Correspondingly, the extractions of geometric parameters of discontinuities were performed following manual identification (Maerz et al., 2013). Therefore, the time cost for data processing in lab is always more than that of data collection for manual analysis in the field.

Subsequently, the focus on LiDAR for discontinuity analysis has been evolving from basic applications to the development of intelligence algorithms to detect discontinuities and extract parameters automatically or semi-automatically. Several software packages have been developed: Split-FX (Slob et al., 2005), Coltop-3D (Jaboyedoff et al., 2012), FSS (Liu et al., 2014), DiAna (Gigli and Casagli, 2011), PlaneDetect (Lato and Vöge, 2012), DSE (Riquelme et al., 2015), FACETS (Dewez et al., 2016). Simultaneously, mathematical statistics analyses were employed to recognize points located on the discontinuities from the original point cloud, including random sample consensus (RANSAC) (Ferrero et al., 2009), clustering (Ge et al., 2017; Chen et al., 2016), kernel density estimation (KDE) (Riquelme et al., 2014), and principal component analysis (PCA) (Gomes et al., 2016). Currently, scholars are paying closer attention to the region growing (RG) algorithm, which is an image segmentation method to separate the interested objects from the background by examining the difference between the seed and neighboring pixels, depending on similarity criterion. Leng et al. (2016) integrated the Hough transform (HT) and RG algorithm to detect planes from multiscale point clouds, and HT served to estimate the initial seed (growing unit). The RG algorithm was employed to detect the discontinuity trace (fracture line) from the point cloud based on a triangulation structure model (Li et al., 2016; Cao et al., 2017). The RG algorithm was also introduced to extract discontinuity surfaces from the point cloud according to local surface normals and/or curvature (Vöge et al., 2013; Wang et al., 2017a,b), or point normals (Ge et al., 2017). These methods have achieved good results, and focused on the application of the conventional RG algorithm for discontinuity identification. However, it is well known that point data volume produced by LiDAR greatly depends on scanning size and point spacing (resolution), and 100 K million points would be acquired for large-scale intensive scanning. In this case, the identification will not meet the requirements of high computational efficiency using the RG algorithm. The aim of discontinuity identification is to serve as an upcoming geometric parameters measurement; unfortunately, most previous works lack adequate research on measurement procedure following identification, and a few parameters are acquired, such as orientation and trace length. To better understand the mechanics behavior of jointed rock masses, more parameters need to be derived from the point cloud (Gigli and Casagli, 2011). Furthermore, for irregular and complicated discontinuities in shape and scale, it is very difficult to determine the threshold that is a common parameter for the RG algorithm, and little work has been conducted to provide suggestions for choosing an appropriate threshold when detecting discontinuities from the point cloud.

This article aims to develop an automatic procedure to detect discontinuities and measure associated geometric parameters from a point cloud acquired by LiDAR. Newly created grid data and a modified region growing (MRG) algorithm were used to promote efficiency of discontinuity identification, and four primary geometric parameters of detected discontinuities were calculated rapidly. Then, the general principles for choosing a reasonable threshold T were provided through sensitivity analysis and analytic geometry.

2. Methodology

Two attempts were implemented primarily to enhance the computational efficiency of the RG algorithm. First, a grid data structure with the same interval was employed to store the point cloud. In this format, data access can be performed more efficiently based on the rows and columns in the grid. Second, the criterion in the MRG algorithm, which is utilized to examine similarities between seed and adjacent points, was improved to increase the growth rate. The following subsections provide detailed information about the methodology developed in this paper.

2.1. Creating grid data

Grid data where points are evenly spaced create more efficient data processing and data retrieval. Notably, the point cloud acquired by LiDAR typically is placed in an irregular manner, rather than with the same intervals. The density of the point cloud has a close relationship with the topography of the rock outcrop, presence of obstacles or occlude areas, measurement errors, etc., and it is almost impossible to sample the point cloud of rock outcrops uniformly. Thus, it is unavoidable that holes (sample gaps) are frequently observed in a raw point cloud where data are missing. These spare points will affect the precision of discontinuity recognition and increase the computational time (Li et al., 2016). To make the point cloud homogeneous and save time, there is a better way to create the grid data of the point cloud to fill these sampling gaps by interpolating algorithms (Fig. 1). Additionally, in the format of grid data, the point cloud is defined as an array with equal intervals, where rows and columns are associated with the point spatial positions. In this manner, the point considered can be conveniently referenced by its column and row number.

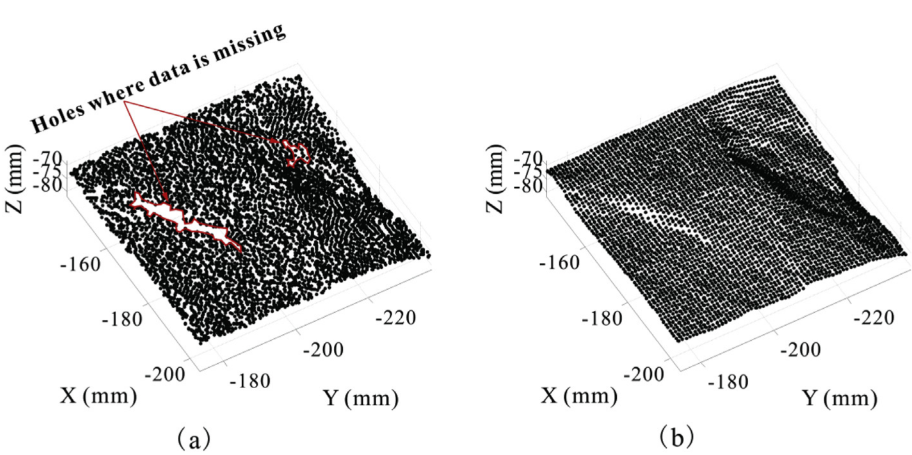

Fig. 1. Comparison between raw point cloud (a) and point cloud after gridding (b).