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Semi-automatic extraction of rock discontinuities from point clouds using the ISODATA clustering algorithm and deviation from mean elevation

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ABSTRACT

This paper presents a methodology for semi-automatic extraction of rock discontinuities from point clouds on the resulting 3D digital surface models of rock masses acquired by terrestrial laser scanning or photogrammetry. First, point clouds need to be pre-processed to generate a digital elevation model from a 3D digital surface model of a rock mass. Second, co-directional features of rock discontinuities are identified by classifying the standard deviation of the elevation, slope aspect and slope gradient of raster grids in a digital elevation model using the Iterative Self-organizing Data Analysis Techniques Algorithm (ISODATA). Third, planar features of rock discontinuities are inspected by judging whether the value range of the deviation from the mean elevation (DEV) in the classified subset of raster grids is between + 1 and − 1 using the Topographic Position Index of terrain analysis. Fourth, point clouds data corresponding to the target surfaces of rock discontinuities are acquired by data post-processing using the ArcToolbox of ArcGIS. Finally, geological analysis is executed by calculating the geometric features of the extracted point clouds. A case study of a rock slope along a highway is presented using the proposed method, the results of which demonstrate that the proposed method is so rapid and accurate that it could greatly reduce the amount of manual labour, improve the efficiency of surveying, and utilize the powerful terrain analysis and visualization capabilities of ArcGIS to avoid the computational challenges associated with directly analysing point cloud data.

1. Introduction

Collecting geological information on rock discontinuities is difficult, time-consuming, and often dangerous when using field mapping and handheld direct measuring devices with a scan-line method or a window method that require direct access to the rock face, especially in steep, inaccessible areas.[1–4] Recently, several developed techniques, such as digital photogrammetry[5–8] and terrestrial and aerial LiDAR,[9] have enabled the construction of 3D point clouds of rock surfaces to rapidly obtain 3D geometric information about inaccessible terrain and rock exposures. The virtual geometry of rock faces and terrains formed by this dense point clouds allows engineers to perform the information extraction on a computer with the aid of a mathematical algorithm. However, there is an intractable technical bottleneck in that improvements in the automated extraction of rock discontinuity parameters are needed to gain maximum value from these surface models.[10]

Several approaches have been used to extract rock discontinuities from point clouds by creating 3D surface models of the rock masses. First, the simplest approach for viewing point clouds is to manually select at least three points on the target plane using commercial software, such as Cyclone,[11–13] Vulcan,[14] Jointmetrix3D,[15] Surpac,[16] Sirovision,[17] 3DM Analyst,[18] or 3DGeomec.[19] However, this approach is time-consuming and laborious when analysing numerous rock discontinuities with complex distributions. Second, geological information about the rock discontinuities can be acquired through statistical analyses of the geometric features (normal vectors) of triangular mesh units

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in a TIN generated from point clouds, such as the stereonet method[11,20] and a data clustering algorithm.[20,21] However, this method only provides statistical results and not the spatial distribution of rock discontinuities. Meanwhile, the statistical results are likely influenced by the meaningless data of non-discontinuities. Third, rock discontinuities can be automatically or semi-automatically extracted by identifying the principal curvature changes of the vertices[22] or by searching for the best-fit planes[9,23] by moving a sample window or cube on the point clouds using geometric regional trend analysis software, such as PlaneDetect,[20,24] DiAna 3D,[9] Split-FX[25,26] or Coltop 3D.[27] The accuracy of these approaches is severely susceptible to spurious points caused by vegetation or other objects captured in the point clouds. The size of the sample window or cube is difficult to determine and needs to be adjusted according to the characteristics of the rock discontinuities. If the cube dimension is too large, small-scale discontinuity surfaces will be omitted; if the cube dimension is too small, some pseudo-surfaces will be counted in the extracted results.

This study aims to identify the advantages of statistical analysis on the clustering and feature extraction of geometric contours. Previous literature[28] has discussed a similar idea as this study; however, it only focused on the co-directional features of discontinuities with different orientations, but not their planar features, which mistook the identities of discontinuities and rock faces. By using the clustering algorithm on the standard deviation of elevation, slope aspect and slope gradient based on the Iterative Self-organizing Data Analysis Techniques Algorithm (ISODATA), a semi-automatic method for extracting the exposed surface of rock discontinuities from point clouds by identifying co-directional features is proposed. Planar features of rock discontinuities are quantifiably judged by the deviation from the mean elevation (DEV). Geological information of rock discontinuities can be obtained by analysing the geometrical features and spatial relationships of those extracted point clouds. The proposed method is applied to a Mingtang Mountain Tunnel project and verified using a traditional method.

2. Methodology

A 3D digital surface model transformed from point clouds acquired by terrestrial laser scanning or photogrammetry is composed of triangular mesh units in a TIN. In a 3D digital surface model of a rock mass, rock discontinuities are represented as different groups of gathering triangular mesh units with near-identical normal vectors (co-directional features) meeting a certain limitation of undulation (planar features). The goal of this study is to identify, classify, and extract those triangular mesh units with co-directional and planar features by developing a series of algorithms using the powerful terrain analysis and visualization capabilities of ArcGIS software.[29]

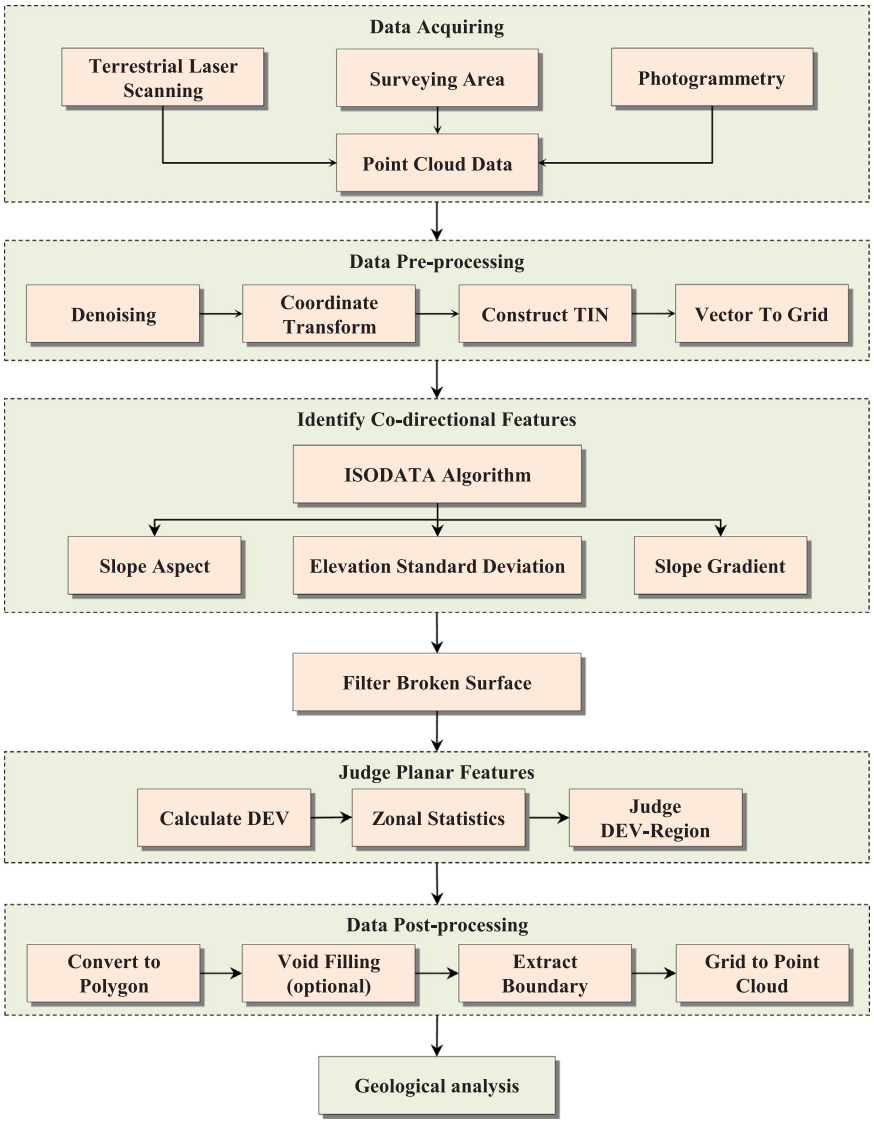

Fig. 1. Flowchart of the proposed method.