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Research paper

A trace map comparison algorithm for the discrete fracture network models of rock masses

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ABSTRACT

Discrete fracture networks (DFN) are widely used to build refined geological models. However, validating whether a refined model can match to reality is a crucial problem, concerning whether the model can be used for analysis. The current validation methods include numerical validation and graphical validation. However, the graphical validation, aiming at estimating the similarity between a simulated trace map and the real trace map by visual observation, is subjective. In this paper, an algorithm for the graphical validation of DFN is set up. Four main indicators, including total gray, gray grade curve, characteristic direction and gray density distribution curve, are presented to assess the similarity between two trace maps. A modified Radon transform and loop cosine similarity are presented based on Radon transform and cosine similarity respectively. Besides, how to use Bézier curve to reduce the edge effect is described. Finally, a case study shows that the new algorithm can effectively distinguish which simulated trace map is more similar to the real trace map.

1. Introduction

Rock mass consists of fractures and blocks cut by the fractures. Fractures have a significant impact on the mechanical and hydraulic characteristics of a rock, usually make a rock mass instable (Park, 2013; Rossmanith, 2014). In different geologic environments, they vary greatly in many aspects, such as size, orientation and spatial distribution. In geology, they can reflect the discontinuity, heterogeneity and anisotropy of rocks and have a significant influence on their mechanical characteristics and hydraulic characteristics. Thus, characterization of rock fractures in terms of the orientation, spacing, size, aperture, etc., is a basic step in rock engineering design (Han et al., 2016).

With the development of mathematical geology and computer technology, researchers tend to incorporate fractures with terrain models and stratum models to make a more elaborate model, called discrete fracture network (DFN) model (Herbert, 1996). For example, Cédric Lambert et al. (2012) simulated a DFN model based on the Baecher disk model to analyze rockfall hazard. Li et al. (2017a) proposed an enhanced polyhedral simulation to identify complex blocks and block-groups. Li et al. (2017b) set up an algorithm for calculating the connectivity parameters of fractures in rock masses based on three-dimensional fracture networks. Ni et al. (2017) also used DFNs to create a more elaborate model, which estimates the representative elementary volume of a rock mass.

Currently, fracture definitions and DFN modelling are recognized as an effective approach to study rock mass structures (Xu and Pruess, 2001; Li et al., 2017a), and the later are used more widely. In this research, we set our sight on the validation of DFN modelling. Although DFN modelling has been put forward for a long time, it is always based on stochastic simulation. Thus, the DFN model will not always match reality. For this reason, validation methods should be employed to ensure the validity of the models. Generally, there are two kinds of methods to validate the models: numerical validation and graphical validation. Most numerical validations are based on statistics. In numerical validations, data from the stochastic models are collected after statistical analysis and are compared with the measured data; it includes the orientations, density, and trace lengths. During the analysis, stochastic models should have the same distribution characteristics with measured data (Merrien-Soukatchoff et al., 2012; Guo et al., 2015a, 2015b; Mendoza-Torres et al., 2017; Wang et al., 2004). As for the graphical validation, the analysis procedure lacks theoretical support, in most cases. Graphical validation is simply based on visual observations: by directly comparing the real trace map and the corresponding simulated trace map to obtain a qualitative judgment (Guo et al., 2015a, 2015b; Li et al., 2017a). Since there are no standards to determine the similarity between a real trace map and a simulated trace

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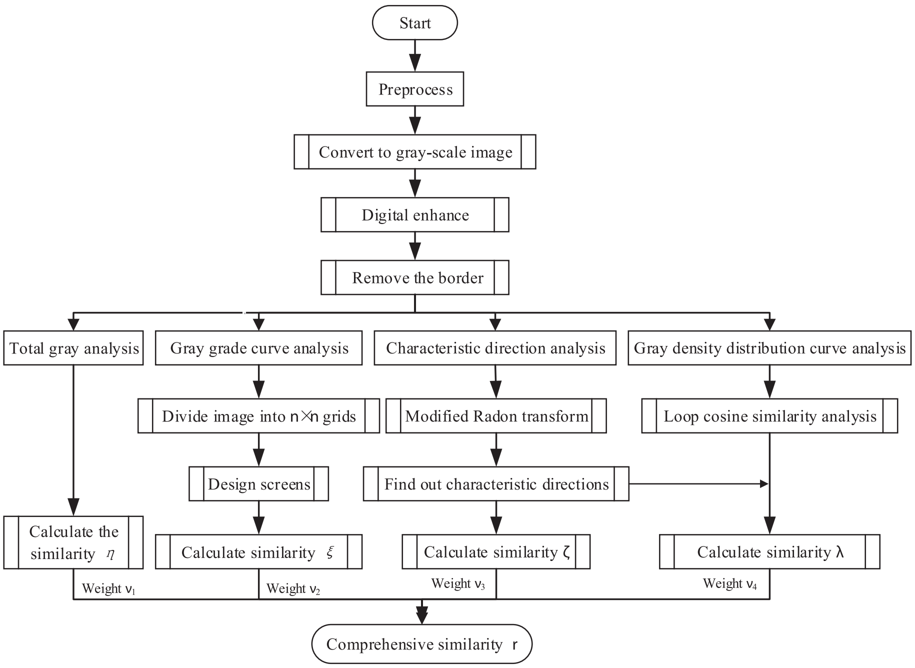
Fig. 1. Flow chart of the algorithm.



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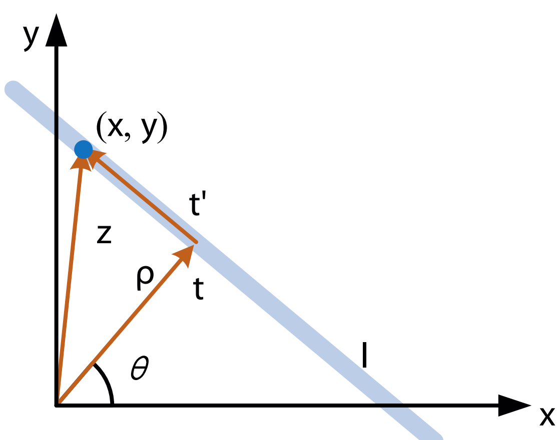

Fig. 2. Coordinate system for defining the Radon transform.

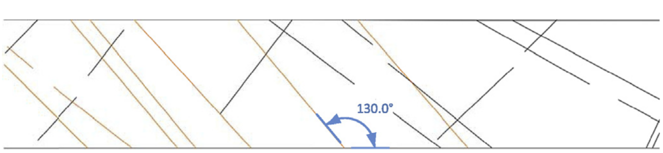

Fig. 3. A real trace map example.

map, different observers may give different validation results. However, few researchers have set their sights on this topic and been working on improving the graphical validation method (Cacas et al., 1990). With the development of digital image processing technology and artificial intelligence, we put our focus on this method.

Many researchers have studied trace maps with the help of digital image processing technology. For example, Fitton and Cox (1998) developed a general and robust procedure to extract linear features of all scales from geoscientific datasets. Kemeny and Post (2003) described a computer approach for estimating three-dimensional fracture orientations from two-dimensional fracture trace information gathered from digital images of exposed rock faces. Lemy and Hadjigeorgiou (2003) presented a digital face mapping methodology that can generate trace maps according to photographs of surfaces of rock mass. Ferrero and Umili. (2011) proposed a method to estimate characteristics of rock mass from orthophotographs. Gigli and Casagli (2011) presented a Matlab tool that can calculate the parameters and features of rock mass just according to Light Detection and Ranging (LiDAR) point clouds. Riquelme et al. (2014) also proposed a method for the semiautomatic calculation of the orientations and position of rock mass discontinuities from LIDAR data. Zeeb et al. (2013) presented the software FraNEP (Fracture Network Evaluation Program), which automatically analyses the statistical properties of 2D fracture networks based on trace maps. Cao et al. (2017) set up a method to identify structural fractures directly from three-dimensional point clouds and evaluate the fracture distribution. Clearly, most of the methods focused on the detection of fractures from digital images, rather than for geological models. Aydin and Caers (2013) set up a method based on image transform to analysis geological models. However, its purpose is to determine the complexity of a model that used in flow analysis, different from graphic validation. Umili et al. (2013) provided an automatic method for discontinuity trace mapping and sampling with a rock mass digital model to automatically identify discontinuity traces from digital surface models. Li et al. (2016) also set up a similar method. However, these can't be used for validating the model, either.

In this paper, we set our sight on the graphic validation, aiming at automatically distinguishing which simulated trace map is more similar to the real trace map. In this research, a set of image preprocessing methods are firstly described. Then, four main indicators, including total gray, gray grade curve, characteristic direction and gray density distribution curve, are presented to assess the similarity between two trace maps. For analyzing the characteristic direction, a modified Radon transform equation is presented based on Radon transform, and Bézier curve is adopted to reduce the edge effect. For analyzing the gray density distribution curve, the loop cosine similarity is put forward based on cosine similarity. Finally, a case study is carried out. The result shows