# Semi-automatic mapping of discontinuity orientation at rock exposure by using 3D laser scanning techniques

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**Abstract:** A semi-automatic methodology is presented in this paper for 3D mapping of discontinuity orientation by using 3D laser scanning data. Comparing to traditional methods, the 3D laser scanner can quickly record a great amount of digital 3D information of an object. The scanner used in this study can rotate 360 degrees in both horizontal and vertical directions with a scanning radius of 57 meters. The area of a scanning field can also be adjusted by the computer program. Each scan takes just a few minutes with a high-speed sampling rate up to 625 000 points per second, and covers up to hundreds of square meters with the optimal scanning resolution about 3 mm. Each scanning point was recorded by 4 parameters, i.e. the 3D co-ordinates (X, Y, Z) and the reflex intensity. Therefore, the rock faces can be quickly recorded in three dimensions with 3D digital model and image (3D grey-scale image). By measuring a few reference points for each scan, the rock face can be transformed into a geo-reference co-ordinate system, which enables us to locate any parts of a rock face in a real space. Therefore, 3D measurement and documentation of a rock face can be more quickly recorded in 3D visual and digital formats.

Based upon the recorded co-ordinates of scanning points, the geometrical features of rock faces can be characterized. In the case study, a semi-automatic methodology for measuring discontinuity orientation has been evaluated. Although it is not fully automatic mapping, it can utilize both personal background knowledge and the advantage of computer resources, so the obtained results can be safely used in a practical rock engineering project.

The more detailed results presented in this paper show a promising method for 3D mapping and documentation of rock faces and tunnels, and might also provide a way to solve the well-known bottleneck problem for data acquisition in rock engineering.

**Résumé:** Une méthodologie de semi-automatic est présentée en cet article pour tracer 3D de l'orientation de discontinuité en employant des données de balayage du laser 3D. Comparant aux méthodes traditionnelles, le module de balayage à laser 3D peut rapidement enregistrer une grande quantité de l'information 3D numérique d'un objet. Le module de balayage utilisé dans cette étude peut tourner 360 degrés dans des directions horizontales et verticales avec un rayon de balayage de 57 mètres. Le secteur d'un faisceau de balayage peut également être ajusté par le programme machine. Chaque balayage prend juste quelques minutes avec un taux à grande vitesse de prélèvement jusqu'à 625 000 points par seconde, et couvre jusqu'aux centaines de mètres carrés de résolution optimale de balayage environ 3 millimètres. Chaque point de balayage a été enregistré par 4 paramètres, c.-à-d. le 3D coordonne (X, Y, Z) et l'intensité réflexe. Par conséquent, les visages de roche peuvent être rapidement enregistrés dans trois dimensions avec le modèle 3D numérique et l'image (image 3D à fond gris). En mesurant quelques points de référence pour chaque balayage, le visage de roche peut être transformé en geo-référence coordonnent le système, qui nous permet de plac toutes les parties d'un visage de roche dans un vrai espace. Par conséquent, la mesure 3D et la documentation d'un visage de roche peuvent plus rapidement être enregistrées dans des formats visuels et numériques de 3D.

Basé sur enregistré coordonne des points de balayage, les dispositifs géométriques des visages de roche peut être caractérisé. Dans l'étude de cas, une méthodologie de semi-finale-automatic pour l'orientation de mesure de discontinuité a été évaluée. Bien qu'elle ne soit pas tracer entièrement automatique, elle peut utiliser des connaissances de base personnelles et l'avantage des ressources de informatique, ainsi les résultats obtenus peuvent être sans risque employés dans un projet pratique de technologie de roche.

Les résultats plus détaillés présentés dans cette exposition de papier une méthode prometteuse pour tracer de 3D et documentation des visages et des tunnels de roche, et pourraient également fournir une manière de résoudre le problème bien connu de goulot d'étranglement pour l'acquisition de données dans la technologie de roche.

**Keywords:** semi-automatic, 3D, laser scanner, discontinuity orientation, rock face, rock engineering

## 1. INTRODUCTION

In a rock engineering project, fracture mapping is one of the important steps, which provides the input data for further rock mechanics analysis, rock engineering design and numerical modelling. Currently, fracture mapping at rock faces is typically performed by using compass and inclinometer, and documentation by recording information on a notebook and photographing with a camera. Although these so-called traditional methods are now still used in most rock engineering projects, the quality and quantity of data are sometimes unable to meet the requirement in rock engineering projects. The most well known drawback for traditional methods is that too much personnel work is involved in the in-situ data acquisition procedure, which is time-consuming, not accurate enough, sometimes difficult and dangerous to reach the rock faces physically. In addition, the way of data recording and storing cannot make the full use of modern IT and computer technology to speed up the data processing, and then provide the input data in a required format for further analysis and design. Therefore, it has been recently realized that applying a new method for in-situ data acquisition is the key to solving the bottleneck problem for improving rock face mapping in terms of both the quality and quantity of data.

In order to avoid the drawbacks of the traditional method, a new method in the authors' opinion must have the following important features: i) quick capture of data in the field; ii) digital collection of data in order to utilize the modern computer resources to speed up the procedure of data capturing and processing; iii) access to interactive operation of the data so that the operator's background knowledge and experience can be fully utilized to observe the complicated phenomena at the jointed rock mass, and then obtain the required information for rock engineering applications; vi) maintaining a certain level of accuracy for different rock engineering applications; v) the possibility of capturing data in 3D over a range of distances without physically contacting the rock faces.

In recent years, the efforts of developing new techniques for in-situ data collection at rock faces have progressed. Techniques, such as photogrammetry (e.g. Harrison, 1993; Coe, 1995), image processing (e.g. Post and Kemeny, 2001), total station (Bulut and Tudes, 1996; Feng, 1999) and laser scanning (Feng 2001, Slob et al., 2002, 2004), have been tested for measuring different joint parameters and documenting rock faces. The presented method has applied a newly developed 3D visual laser scanning technique for characterization and documentation of joint and jointed rock masses at rock faces. Compared to other laser scanning systems, the presented phase-based scanning system has some features, which are more suitable for rock face mapping and documentation, e.g. high scanning speed, high resolution, large scanning scope. As both co-ordinates and reflex intensity are simultaneously measured for each point, rock faces can be digitally recorded in a three-dimensional visual format. By using specially developed software, rock faces, both at road cuttings and inside tunnels, can be characterized in a 3D digital model with the corresponding 2D and 3D grey-scale laser images. Therefore, these features avoid the drawbacks of traditional methods, and meet the special requirements for a new method applying to rock face mapping. In the case study, fracture orientation was semi-automatically measured by a special developed program with laser data. Results will be presented in this paper.

## 2. LASER SCANNING PRINCIPLE AND RAW DATA CAPTURE

### *2.1 Laser scanning principle*

The in-situ 3D-laser scanner, named Leica HDS4500, was used in this study. It was initially developed for mobile robot navigation and inspection tasks, but now also for other applications related to 3D mapping and modelling. The existing 3D laser scanning systems in the market are usually designed based upon three scanning principles, e.g. triangulation, pulse-based and phase-based techniques. The presented scanner was specially designed using a phase-based technique for high-speed, high-performance and eye-safe scanning tasks with indoor and outdoor medium-range applications (0.1 - 54 m). The scanning device (Figure 1a) consists of two major components: the single-point laser measurement system and the mechanical beam deflection system (Figure 1b). The point-sensor laser measurement system comprises the laser head, the high frequency unit and the signal processing unit for data pre-processing. This part controls the emitting, receiving and processing of the laser beam. By using the dual frequency AMCW (amplitude-modulated, continuous-wave) method in conjunction with a coaxial transmitter/receiver design, the receiver measures the phase difference between the original and returned laser signal at both modulation frequencies and the power of the reflected laser light, both range and reflectance of a target point can be obtained. So, not only 3D point cloud but also 3D image can be captured. In addition, it is no problem to scan an object in the dark because of the use of infrared laser light. The scanning distance is in the range of 0.1 – 54 m with an optimal accuracy of 3 -- 5 mm (Mettenleiter M, et al., 2000; Langer D, et al., 2000). The mechanical beam deflection system consists of a special mirror and the motor control unit. The mirror is used for deflecting the emitted laser beam generated from the laser head at the bottom, and collecting the back-scattered laser light cone. The motor controls the mirror rotation in the horizontal and vertical direction, which can make a scanning field overview of 360 degrees in azimuth and 310 degrees in elevation. So, a large scanning scope can be scanned simultaneously. Each scan takes about 1-13 minutes (depending on the resolution) with the high sampling speed up to 625 000 points per second. Therefore, it is possible to quickly capture a large area of a rock surface in the field.

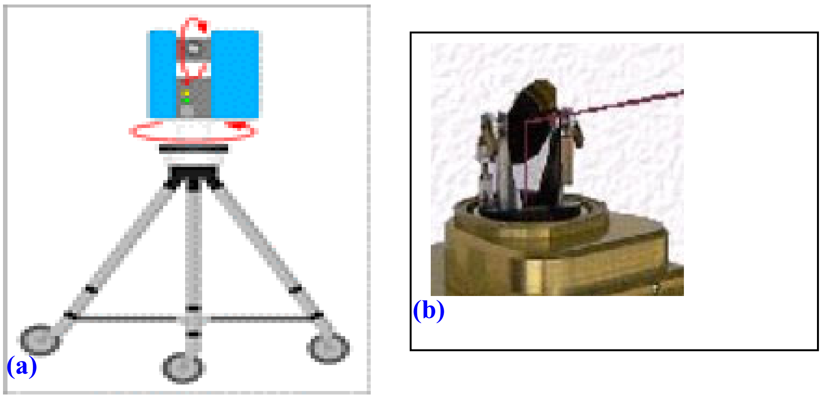


**Figure 1**. Imager 5003 3D laser scanner (a) and its scanning head (b)

## *2.2 Raw data capture*

As mentioned above, the scanner was intentionally designed to measure the position and the reflectance intensity of each point simultaneously. Therefore, the 4-column (e.g. X-Y-Z-Intensity) raw data can be recorded. Comparing to other 3D laser scanning systems, the raw data can be displayed in four different formats: i) clouds of points with 3D co-ordinates shown in Figure 2a; ii) 3D grey-scale image generated from both 3D co-ordinates and corresponding reflectance intensity values shown in Figure 2b; iii) 2D grey-scale image created from reflectance intensity shown in Figure 2c; iv) 2D grey-scale range image created from reflectance intensity shown in Figure 2d. In this case, a scanned object can be displayed not only geometrically but also visually. Therefore, the scanner may also be referred to as a 3D visual laser scanner, which is specially useful for geological mapping and documentation.

In some cases, if more than one scan is required, several control points must be surveyed by a total station, and then all scans can be registered into the same co-ordinate system for further data processing and modelling.

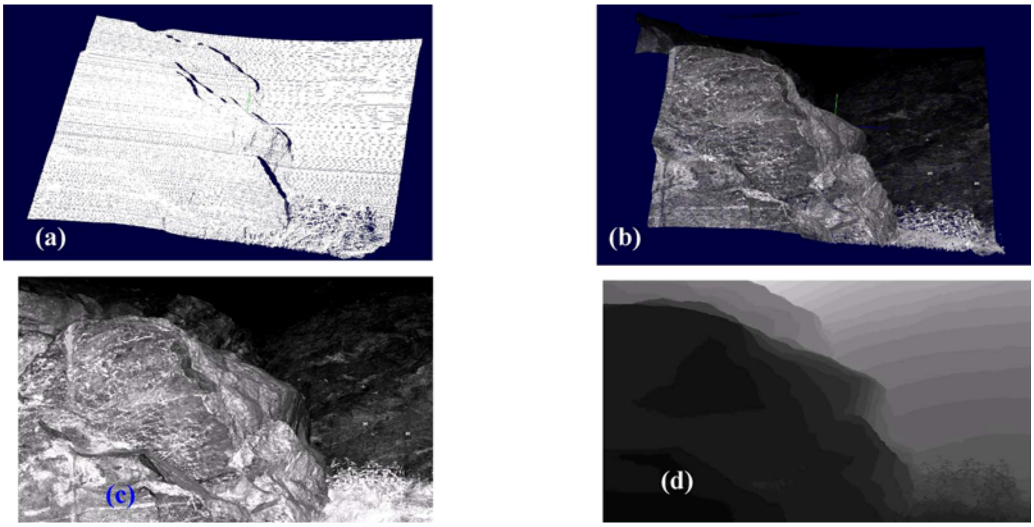


**Figure 2**. Scanning results of rock fracture surface: (a) 3D co-ordinates of target points; (b) 3D model image; (c) grey-scale image of reflectance, (d) grey-scale image of range.

# 3. SEMI-AUTOMATIC MEASUREMENT OF FRACTURE ORIENTATION

By using the presented method, orientation of a fracture plane (e.g. dip and strike) can be determined interactively or semi-automatically from the 3D laser scanning data. Although taking slightly longer than fully-automatic methods, the presented method aims to not only make use of the advantage of modern computer techniques, but also enable the operators to utilize their geological background knowledge to control the mapping results. A typical mapping procedure of this method is taken by the computer software as a virtual mapping platform, but interactively performed between the computer and the operator, as follows: 1) A part of rock surface is selected from the whole 3D scanning model by the operator; 2) A fracture exposed on the scanned rock surface is chosen, and the exposed fracture surface marked interactively by the operator; 3) The best-fit fracture plane is automatically calculated by the computer program, and its fracture orientation calculated.

In a case study, when a rock face is scanned, the data can be oriented and transformed into a known geo-reference co-ordinate system. By using the specially developed software, a fracture surface can be well fitted from a selected 3D point cloud to a best-fit plane (Figure 4b) in the 3D laser image (Figure 4a). As the software enables the operator to freely rotate and move the best-fit plane in the 3D laser image or point cloud, the fracture plane can be interactively determined by the operator, which is similar to taking a notebook as a reference plane for measuring fracture orientation in the field. Therefore, orientation of fracture planes can be semi-automatically determined, which means that the geologists select the representative fracture planes in 3D laser image, and the specially developed software will calculate the required parameters of the selected fractures. In particular, a 3D solid model of different fracture sets can be directly obtained (Figure 4c-d), which might be useful for design and numerical modelling.

# 4. DISCUSSION AND CONCLUSIONS

In this paper, a new 3D visual laser scanner was introduced for documentation and geological mapping at rock faces. The purpose is to investigate the applicability of the new method for improving the quality and quantity of rock face mapping data for further analysis in rock engineering.

The case study shows that the presented technique enables one to capture 3D data of rock faces with high sampling speed and good resolution, especially the 3D laser image which can help geologists to perform rock face mapping in a 3D digital model, and speed up the data processing procedure. Although it is semi-automatic, it is easy for the operator to control the mapping results. In this case, the fieldwork can be quickly performed without physically touching the rock faces. The captured data can be stored in different digital formats and registered into a geo-reference co-ordinate system as a database for retrieval of information.

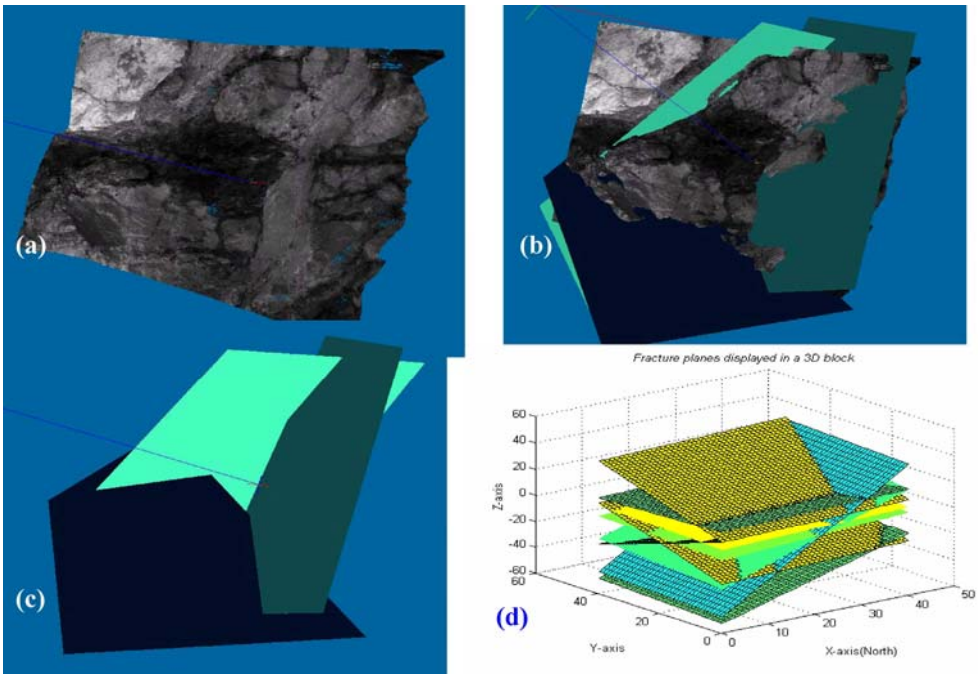


**Figure 4**. (a) 3D laser image; (b) fracture planes generated from 3D laser image; (c) 3D solid model of fracture planes; (d) Fracture sets in a 3D block.

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