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Photogrammetry approach on geological plane extraction using CloudCompare FACET plugin and scanline survey

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Abstract: Photogrammetry advancement in the field of geotechnics is able to provide useful preliminary data in a short time and with minimum resources. The data acquisition for photogrammetry processing was done utilizing the imagery from a low-cost unmanned aerial vehicle (UAV). Commercial drone by DJI, Phantom 4 Pro was used to take aerial and side images of the rock slope. Good overlapping of the images is very important to generate a very dense 3D model. Ground control point was established to georeferenced the output of photogrammetry, so that it represents the real site scale and coordinates. Photogrammetry using structure from motion technique (SfM) is able to generate three-dimensional model of the specified study area. 3-D model of the rock slope was analyzed to extract the geological planes using CloudCompare software with the aid of FACET plugin. 3-D dense cloud point generated from the photogrammetry process was the input file to the CloudCompare software. Traditional method of using scan line survey was carried out to check the adequacy of the geological plane extraction data from photogrammetry survey output. Extraction of geological planes through FACET plugin provides information on major discontinuity sets and the orientation of the planes. Then, the dip/dip direction obtained was compared with scanline survey. The discontinuity datasets obtained from the CloudCompare was compared with the scan line survey. Results showed the difference is not more than 20 %. Therefore, application of photogrammetry through CloudCompare software provides reliable and accurate measurement.

Keywords: Photogrammetry, rock slope, FACET, geological plane extraction, scanline survey

INTRODUCTION

Recent progress in technology have made it possible to use images to model a scene or objects through a process called photogrammetry. Current remote sensing approaches, such as Structure for Motion (SfM) and Terrestrial Laser Scanner (TLS) permits the acquisition of information to be done in a precise and fast way. Photogrammetry can be well-defined as a method that allow quantitative measurements and reconstruction of the geometry of solid objects by the means of photos and other image data. It is a branch of remote sensing that was conventionally developed as a fundamental tool in geodesy and topography but has wide-ranging application beyond these fields (Lillesand *et al.,* 2014). SfM photogrammetry offers the prospect of fast, computerized and low-cost acquisition of 3D information which certainly created interest among professional and researcher (Micheletti *et al.,* 2015; Tannant, 2015). Photogrammetric data processing is desirable to generate a geo-referenced 3D point cloud from the unordered, overlapping, and aerial image acquisition of the earth surface. Existing Structure from Motion (SfM) algorithms automatically extract features in the images, for example, contour lines, edges, and feature points (Siebert & Teizer, 2014). SfM method can produce extremely decimate-scale vertical accuracy even for study areas with complex topography (Westoby *et al.,* 2012). According to Klawitter *et al.* (2017) close range photogrammetry was used for data acquisition and reconstruction of the three dimensional (3D) scene of the rock outcrops.

Discontinuity plays significant role in the strength, stability, deformability and permeability of the rock mass. Hence, the description of discontinuities in rock mass must be accurate to enhance the quality of geological input data for an effective geotechnical assessment (Priest & Hudson, 1981). Discontinuities can be characterized in terms of several parameters such as orientation, spacing, persistence, fracture and shape, connectivity, and aperture coatings. These information can be collected from field surveys by scanline method or aerial surveys or in borehole observations (Singhal & Gupta, 2010). Traditional technique of characterizing the rock slope such as scan line survey which requires the use of geological compass, inclinometer and measuring tape to measure the discontinuities. This method has several disadvantages because rock mass exposures tend to have limited accessibility which can affect the choice of sampling location. Therefore, rock slope characterization using this method is bias, tedious, hazardous, time consuming and expensive. Photogrammetry method to map the discontinuity in the entire topography in 3D can be an alternative. It can eliminate the problems of accessibility, but can collect huge amount of data, resulting in more representative and accurate results of the rock mass discontinuities.

Nevertheless, the dense point cloud from photogrammetry processing will be able to extarct geological planes. An algorithm was developed to extract the geological planes and discontinuities quantitatively which is useful for geotechnical designing work. Geological planes retain the attentions due to its simplest 2D geometric figure and is significant for many applications, mainly in geology. Planes that appear in geological outcrops provide useful information to the practitioner, for example, the sedimentation formation, structural or tectonic history and rock mass quality. Recently, Dewez *et al.* (2016) developed a dedicated structural geology plugin called FACET within CloudCompare which is an open source software. It is mainly to accomplish planar facet extraction in order to compute their dip and dip direction. In this study, dense cloud generated from the photogrammetry processing is exported into CloudCompare software to allow the FACET plugin to extract the geological planes for rock mass discontinuity characterization. Next, the obtained dip and dip direction from the software is compared with the conventionally method of using scan line survey.

METHODOLOGY

The study area is situated at Kuala Perlis, the northern state of Peninsular Malaysia where the construction of a channel to bypass the water from Timah Tasoh Dam to the sea have been completed. The rock slope is mainly made up of karst limestone, excavated for the construction of the channel. The exact coordinate is 6.4428794 latitude and 100.143884 longitude as shown in Figure 1. Bare rock slope terrain and a few discontinuity sets can be observed easily, as shown in Figure 2. The methodology was divided into three phases which is fieldwork data acquisition, processing of digital images and datasets, and scan line survey data acquisition.

Fieldwork data acquisition

The area of interest was firstly identified to position the ground control points (GCP), scale bar and to carry out scan line survey. A total of 10 GCP was identified for this UAV photogrammetry mapping and the coordinates of the points were measured using Leica Viva UNO CS10 single frequency GPS instrument. This GPS equipment will produce an accurate coordinate reading by utilizing Real

Figure 1: Study area location marked on GoogleEarth image (latitude-6.4478794, longitude-100.143884).

Figure 2: Rock slope outcrop and site overview.

Time Kinematic (RTK) method in World Geodetic System (WGS84) standard. Table 1 shows the coordinates reading of each GCP in longitude, latitude and altitude. DJI Phantom 4 Pro version of quadcopter was used to capture aerial and side images. A total of 234 images were captured, 74 aerial images flying at the height of 70 m and 160 images from the side of the exposed rock slope covering an area of 27,700 m^2. Figure 3 shows GCP marked with red marking and the GPS equipment set up. Figure 4 shows the position of images taken by the UAV where blue squares depict the camera positions and orientations.

Processing UAV imagery datasets

Agisoft Photoscan Professional (version 1.4.1) software is used to process the georeferenced images captured by the UAV (Agisoft LLC, 2016). Firstly, the images were imported into the software, followed by alignment of photos where the accuracy is set to high. Then, feature matching scale-invariant feature transform (SIFT) algorithm is followed by a bundle block adjustment. SIFT is an algorithm used to distinguish and describe local features in an imagery. It locates certain key points and then furnishes them with quantitative information which the descriptors used for object recognition. Image content is transformed into local feature coordinates that are invariant to translation, rotation, scale, and other imaging parameters (Lowe, 2004).

Next is the dense geometry reconstruction where it is set to high accuracy and there are 59 million points generated in the dense cloud. The exported output are 3D dense point cloud, Digital Surface Model (DSM) and orthophoto based on the dense 3D geometry. Comprehensive description

Table 1: Coordinates of GCPs.

GCP	Longitude (m)	Latitude (m)	Altitude (m)
P1	100.144337	6.428421	2.493
P2	100.144404	6.428434	1.634
P3	100.144417	6.428742	2.991
P4	100.144744	6.428693	4.131
P5	100.144930	6.428660	3.917
P6	100.145312	6.428645	3.987
P7	100.144622	6.428899	25.246
P8	100.144940	6.428869	25.749
P9	100.144622	6.428998	33.253
P10	100.144784	6.428974	33.657

Figure 3: GCP marked in red and GPS equipment set up.

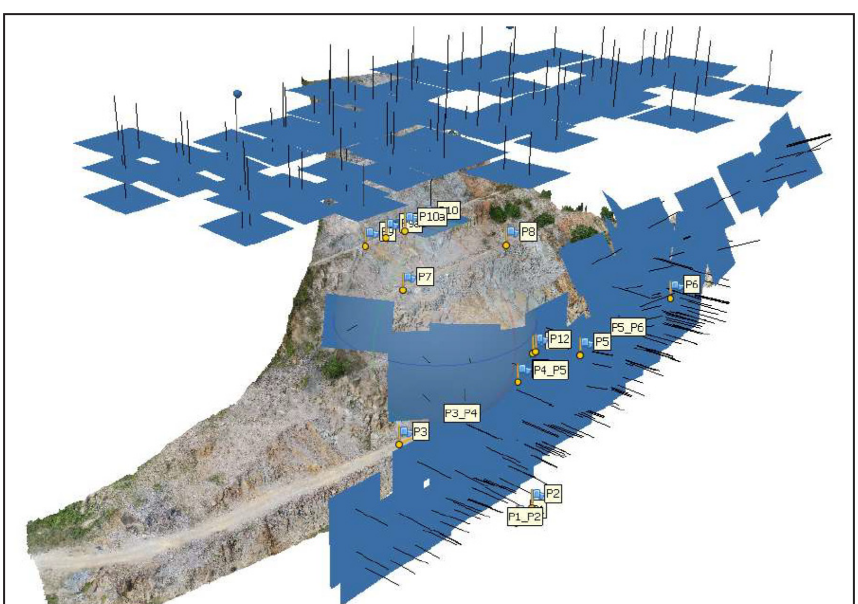

Figure 4: Camera position and orientation of the image capture by UAV.

of the Agisoft Photoscan workflow can be referred to the method established by Lucieer *et al*. (2014) and Agisoft Photoscan User Manual (Agisoft LLC, 2016). The dense point cloud generated and integrated with the ground control point (GCP) is then imported into an open-source software, CloudCompare, with the aid of Facet plugin to extract the geological planes in the rock slope outcrop.

There are two approaches available to extract the discontinuities, which is by using k–dimensional tree (KD) approach, and Fast Marching (FM) approach. Both methods implement at least square fitting algorithm. K-d tree is a space-partitioning data assembly for establishing points in a k-dimensional space. K-d tree method splits the 3D point cloud into a smaller planar patch recursively until the point fits the best-fitting plane. Planar patches are then back grouped into bigger facets as per a co-planarity measure. Then again, FM approach splits the 3D point cloud into littler patches and regroups them. Consequently, every one of the patches will have same size (Tung *et al.,* 2018). Therefore, FM Marching approach was chosen because it is easier and considers few parameters.

After the meshes or facets are extracted, they can be categorized by orientation (dip/dip direction) into single planes and plane families. A stereogram can be delivered which is beneficial for rock slope stability analysis. Query is possible on the stereogram with the outcrop portion being chosen. Lastly, the facets data can be exported into excel file

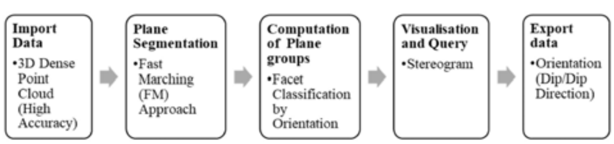

Figure 5: Methodology using FACET plugin in CloudCompare software.

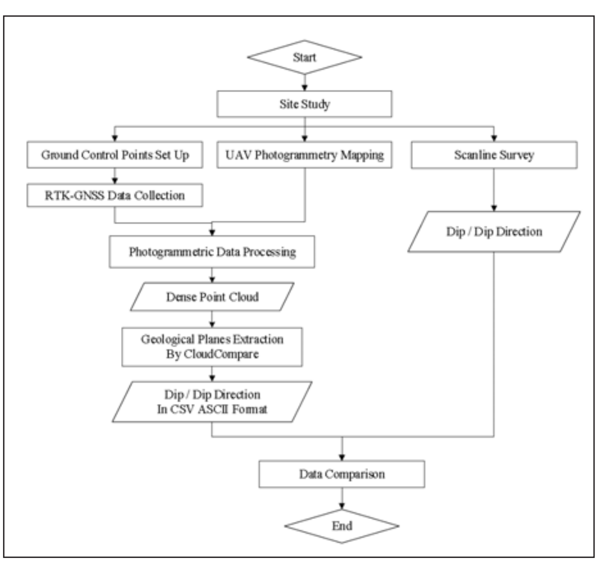

Figure 6: Flow chart of research methodology.

to carry out kinematic analysis. Figure 5 shows the summary of methodology using facet plugin in CloudCompare to extract geological planes from 3D point clouds.

Rock slope discontinuity orientation acquisition

Discontinuity is a plane or surface that indicates a change in physical or chemical characteristics in a rock mass. It can be a bedding plane, joint, fracture or fault plane. In this study, orientation of the bedding plane was measured using scanline survey method. The discontinuity orientations or dip / dip directions of the rock slope were measured along a reference line at 1.70 m above the ground level which was reachable. Geological compass, clinometer and measuring tapes are the tools used for the dip / dip direction measurement. The sampling was taken randomly along the lines due the accessibility to collect the manual readings. The rock slope material is very weak, brittle and loose which can be very risky to collect the manual scanline survey data. Figure 6 summarizes the research methodology in the form of a flowchart.

RESULTS AND DISCUSSION

Two methods were applied in acquiring the orientation of discontinuity joint (dip/dip direction) of the rock slope: manual approach by using scanline survey method and automatic approach by extracting the discontinuity orientation of the rock slope digitally. The scanline survey method is used to verify the reliability and accuracy of the discontinuity orientation extracted digitally.

Extraction of geological planes

In CloudCompare, FACET plugin was used to extract the discontinuities present in the rock mass. 31 million points out of 59 million points belong to the outcrop. After the process of fast marching (FM) approach in plane segmentation, 3852 facets were produced and grouped according to their dip / dip directions. From Figure 7(a) and Figure 7(b), it can be seen that there are two major discontinuity sets: Set 1 (green) and Set 2 (blue). The mean dip/dip direction for Set 1 is 046°/172° as displayed in Figure 8a whereas for Set 2, it is 043°/189° as shown in Figure 8(b). For the entire rock slope, the mean dip/dip direction is 035°/186° as depicted in Figure 8(c). The stereograms shown Figure 8 as exported from CloudCompare and plotted in dip vector mode.

Scanline survey method

The dip / dip direction of the rock slope was measured along the three lines at different elevations as shown in Figure 9. The results of the 30 sets of dip / dip directions were tabulated in Table 2.

Dip / dip direction analysis

Measurement of orientations using scanline survey method was used to verify the accuracy of the extraction of geological planes by FACET plugin in CloudCompare.

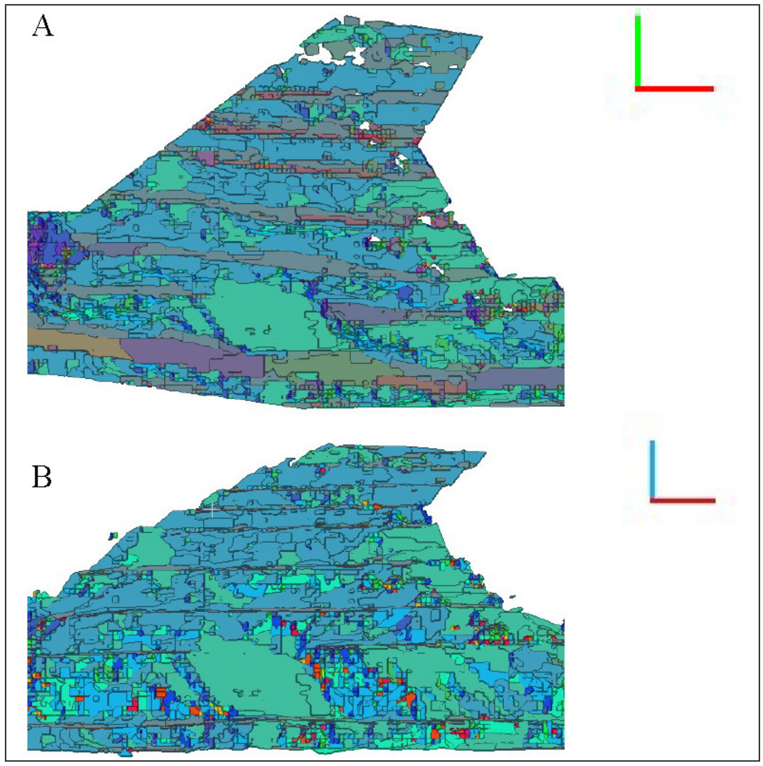

Figure 7: Top view (A) and front view (B) of facets extracted from the 3D dense cloud.

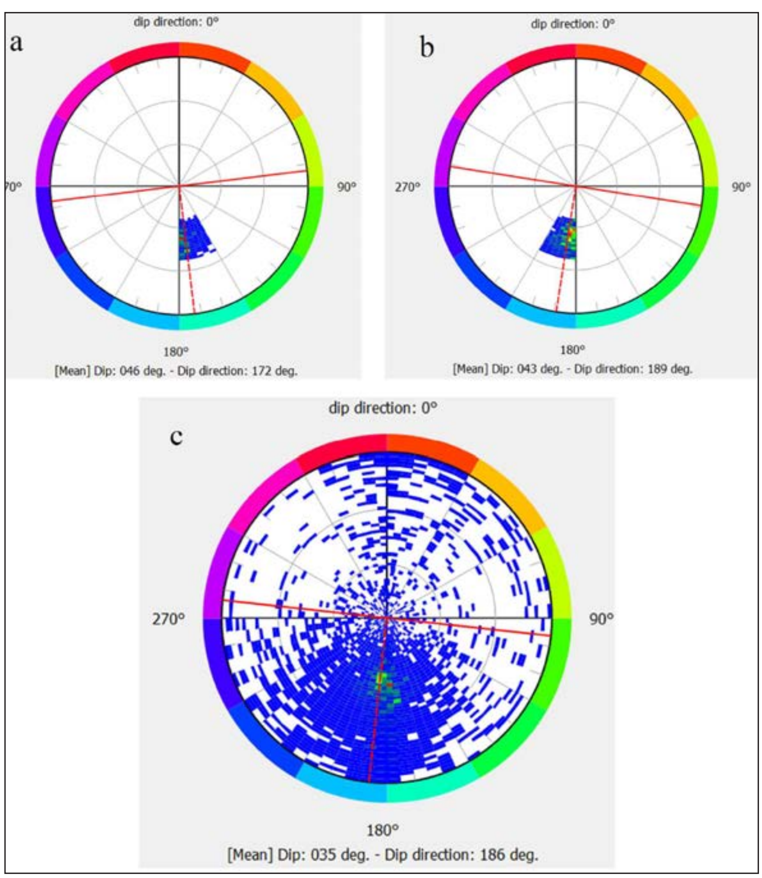

Figure 8: Stereogram (a) Green set, (b) Blue set, (c) Entire rock slope.

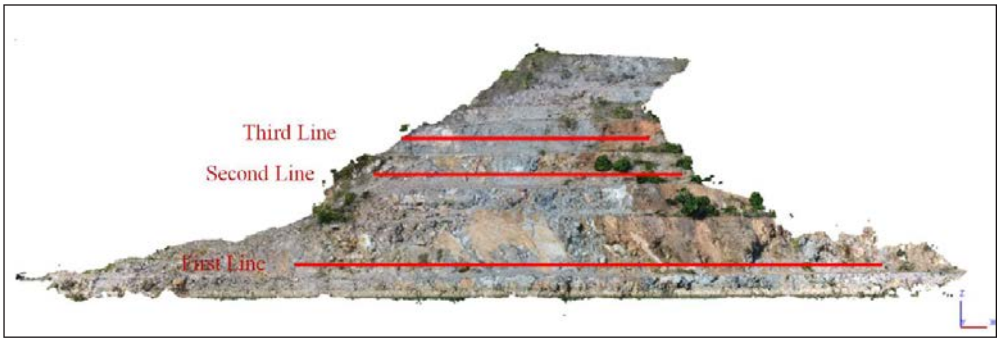

Figure 9: Orientations were measured along the three lines.

Table 2: Comparison of dip / dip direction obtained manually and from software.

Line	Location	Scanline Survey		Extraction from Software	
		Dip Angle (°)	Dip Direction (°)	Dip Angle (°)	Dip Direction (°)
First	1	51	175	49	180
	2	64	170	63	174
	3	60	174	62	171
	4	78	185	76	188
	5	76	185	76	185
	6	64	190	67	193
	7	42	189	40	188
	8	40	181	40	185
	9	57	190	57	193
	10	46	174	44	175
	11	63	187	65	190
	12	55	170	55	174
	13	54	167	59	181
	14	40	155	45	152
	15	52	186	53	184
	16	47	165	42	163
	17	41	174	43	174
Second	1	39	186	42	185
	2	48	176	44	177
	3	41	184	39	188
	4	41	198	38	196
	5	43	186	40	190
	6	39	172	39	179
Third	1	46	171	46	177
	2	39	194	42	189
	3	46	181	47	188
	4	41	192	42	188
	5	40	183	44	179
	6	52	190	50	192
	7	50	174	50	176

The dip / dip direction of the same location was extracted from the software to compare with that obtained manually. The data is tabulated in Table 2.

From Table 2, there is a difference of up to 7° of dip angle and dip direction between the data extracted digitally from the software and manual measurement. Stereogram of orientations measured by scanline survey method and extracted digitally from software are depicted in pole vector mode in Figure 10 and 11 respectively. Both stereograms show a quite similar contours of pole vectors, facing north in the stereogram. The mean dip / dip directions measured by manual measurement is 47°/180° whereas 48°/181° for dip / dip directions extracted from software. The difference is about 1°. Despite of the difference of up to 7° in the individual poles, the results are acceptable and within the tolerance limit for both dip angle and dip direction since the natural outcrop roughness contributes to the variability. Hence, this indicates that FACET plugin in CloudCompare can extract geological planes based on its algorithm. It performed well to map explicitly the entire rock outcrop. All the facets extracted from the entire rock outcrop is useful for further rock slope stability analysis. Figure 12 shows the stereogram of 2933 pole vectors extracted from the entire rock slope with mean set plane of 43°/185°.

Normally, scanline methods are carried out at the human height level from the ground due to accessibility issue to access the higher portion of the rock slope. There might be different orientations at the bottom and upper portion of the rock slope. Thus, without obtaining data from the inaccessible rock slope section, the data collected might be not represent the entire rock slope. Therefore, using UAV photogrammetry as a tool to obtain rock outcrop is a better approach that will provide reliable results and able to make comparison with the scanline survey. Furthermore, the extraction of geological planes mainly depends on the quality of the SfM dense point cloud produced. In this study, high quality dense point cloud is constructed, and the original pixel count is divided by 4 (image width and height each divided by 2). This value indicates that for an image with 20 megapixels, it will be turned into a 5 megapixels' image. Lower dense point cloud density will result in lower quality of planes extraction due to smoothened edge. Textures in the rock mass are not sharp and therefore results obtained will be inaccurate.

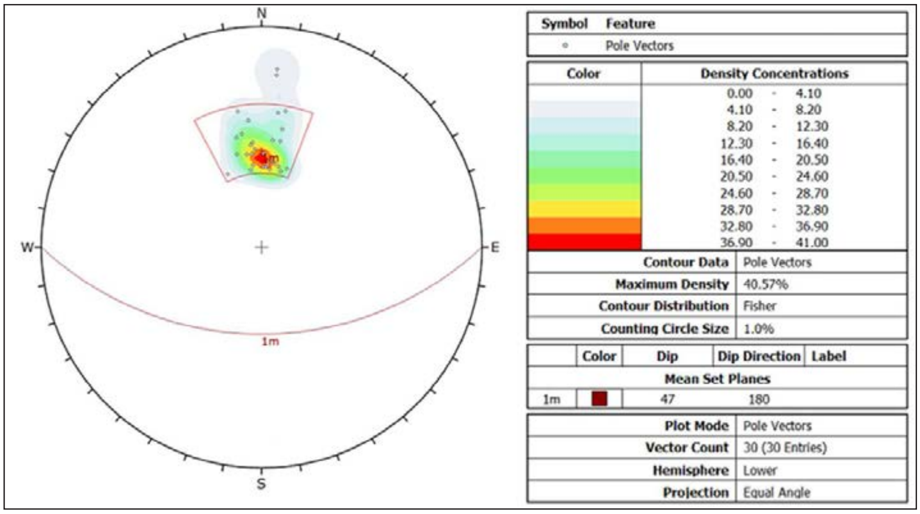

Figure 10: Stereogram of orientations measured by scanline survey method.

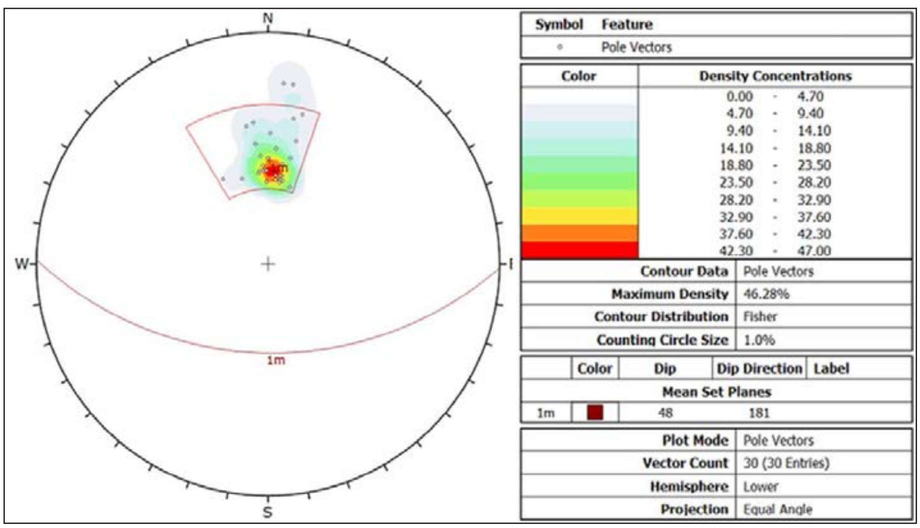

Figure 11: Stereogram of orientations extracted from CloudCompare software.

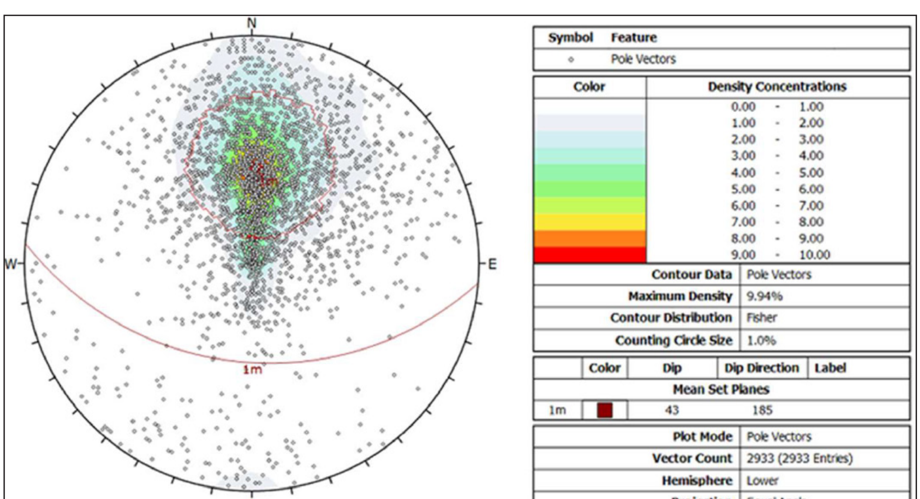

Figure 12: Stereogram of all pole vectors extracted from CloudCompare software.

CONCLUSION

This paper presents a study where the structural geological data collected using scanline survey and compared with geological plane extraction from 3D point cloud data. The comparison between two data sets shows the maximum difference of 7° on individual pole. From the engineering geology the difference of 10° is acceptable. The comparison between photogrammetry technique and scanline survey shows that photogrammetry method able to provide reliable and accurate results to measure dip and dip direction for rock slope characterization. Thus, the queries presented in this paper is practical especially for the rock slope assessment. Computer-generated outcrop geology is an advantageous tool for many applications but it does not substitute the fieldwork.

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