3D rock slope data acquisition by photogrammetry approach and extraction of geological planes using FACET plugin in CloudCompare

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Abstract. Structure from motion (SfM) permits a fast and inexpensive way to obtain data necessary for geotechnical characterization of rock slope. Unlike scanline survey, a traditional technique, SfM can reduce the risk, time, cost, bias in measurement and improve the accessibility, quantity and quality of data collection. A small and low cost Unmanned Aerial Vehicle (UAV), DJI Phantom 4 Pro mounted with 20 megapixels camera is utilized to capture high quality images in this study with Real-Time Kinematic Global Positioning System (RTK-GPS) being used to obtain coordinates of 10 Ground Control Points (GCP) distributed evenly on the rock slope. Images registered and aligned with GCP render better accuracy results compared to images aligned without GCP. With photogrammetry software, dense point cloud, digital surface model (DSM) and orthophotos can be generated. 3D dense cloud reconstructed in the setting of high accuracy, with millions of points of a rock surface, can be imported into CloudCompare to extract the geological planes using FACET plugin. The major discontinuity sets can be observed and the orientation (dip/dip direction) of the discontinuity sets obtained from the algorithm is accurate and reliable for future geotechnical work such as rock slope stability analysis.

Keywords: Unmanned aerial vehicle (UAV), photogrammetry, rock slope, discontinuity

1. Introduction
The current advancement of new remote sensing strategies, such as Structure from Motion (SfM) photogrammetry and Terrestrial Laser Scanner (TLS) permits the obtaining of Earth surface datasets in a precise and fast way. Nevertheless, among the two methods, SfM photogrammetry is an economical, effective and flexible approach to capturing complex topography [1]. UAV with camera mounted on it is used to obtain photogrammetric data. SfM is a photogrammetric approach in producing three-dimensional models of the topography by overlapping and stitching multiple two-dimensional photographs captured from multiple locations. It reconstructs the photographed scene by producing dense point cloud data set aligned with the coordinates obtained from Global Positioning System (GPS) also known as ortho-rectified imagery. The photogrammetry approach are being used widely in geomorphological environments including river bed topography [2], glaciology [3,4], volcanology [5], landslide [6–9] and rock slope mapping for discontinuity characterization [10]. Westoby et al. [11] claims that SfM technique can produce highly decimate-scale vertical accuracy even for study area with complex topography.
Generally, rock masses are heterogeneous and unpredictable as they contain discontinuities such as orientation, size, aperture, surface conditions (roughness and alteration), and frequency. Discontinuity plays an important role in the strength, stability, deformability and permeability of the rock mass. Thus, the description of discontinuities in rock mass must be accurate to enhance the quality of geological input data for an effective geotechnical assessment. The ability of overcoming bias as well as the amount of data collected will have an effect on the discontinuity spacing and trace length measurements [12]. Traditional way of characterizing the rock slope such as scanline survey which uses a compass, an inclinometer and a measuring tape has several disadvantages because rock mass exposures often have limited accessibility which affects the choice of sampling location. As a result, the site investigation is bias, hazardous, time consuming and expensive. Therefore, SfM photogrammetry is a suitable method which can rapidly map the discontinuities in the entire topography in 3D, removing the problems of inaccessibility and bias in collecting large quantities of data, resulting in more representative and accurate results of rock mass properties. However, with the dense cloud, algorithm must be invented to extract the planes and discontinuities quantitatively so that it is useful for geotechnical designing work. Planes in the rock outcrops depict a lot of useful information such as tectonic history, rock mass strength, sediment processes, etc. Researches are still developing to improve the planes extraction automatically using algorithms in different environments [13–17]. Currently, facets, a structural geology plugin, implanted in open-source software, CloudCompare is designed to extract planes from dense point cloud. It is friendly user and can extract planes effectively [18]. Therefore, in this study, SfM using UAV, an alternative method in producing 3D dense point cloud is utilized to map the rock slope for discontinuity characterization. The geological planes are extracted using Facet Plugin in CloudCompare which is a useful and reliable tool. In this paper, the effectiveness of the usage of GCPs used for bundle adjustment is determined. Next, the orientation obtained from the extraction of geological planes using Facet Plugin in CloudCompare is compared with data obtained manually.

2. Methodology
Research area is located at Kampung Wai, Kuala Perlis, Perlis which is known as the most northern state in Peninsular Malaysia. The exact location is having latitude of 6.428794 and longitude of 100.143884 as shown in Figure 1. The rock slope which is made up of limestone is excavated to channel the water from Timah Tasoh Dam to the sea.

Figure 1. Location of the research area (latitude, longitude: 6.428794, 100.143884) (Google Map).
The research area is selected due to the favorable condition of the site for data acquisition by flying UAV. The site has adequate space for flying UAV to capture the photos of the rock terrain (Figure 2a). Besides, the rock terrain is exposed and a few of discontinuity sets can be easily seen as depicted in Figure 2b due to the excavation work for the construction of drainage system from Timah Tasoh Dam to the sea (Figure 2c).

Figure 2. Ample space for flying UAV to capture rock slope images (A), Rock outcrop (B) and Water channelled from Timah Tasoh Dam to the sea (C).

The methodology is based on two phases: fieldwork data acquisition and processing of digital photographs and dataset.

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       |

2.1. Fieldwork Data Acquisition
Preliminary site study is conducted to determine the suitable location to place GCPs. 10 GCPs are distributed on the rock slope and marked by using spray (Figure 3a). Leica Viva UNO CS10 instrument in single frequency with External Antenna AS05, an GPS instrument is used to measure the coordinate of the GCPs in WGS84 (EPSG::4326) coordinate system, utilising Real-Time Kinematic (RTK) technique [19]. A total station is also utilized to obtain the elevation of the GCPs by referring to the nearest temporary benchmark. Table 1 shows the longitude, latitude and altitude of each GCP in the study area. DJI Phantom 4 Pro which is a quadcopter UAV mounted with a 20 megapixels and focal length of 8.8mm camera is then used to fly around the study area. 234 photographs are taken in
total, with 160 photographs captured from the side of the rock slope and 74 photographs are taken from the top with a flying height of 70m above ground level, covering an area of 27700m². Figure 3b shows the density map of the photograph footprints with black dots being the camera locations. More photos are taken from the side of the rock slope to increase the number of photos overlapping, increasing the density of points in the dense cloud and thus enhancing the texture of the 3D model (Figure 3c).

![Figure 3. GCP Markers (A), Density map of photograph footprints. Black dots show the camera locations (B) and Orthographic view of the texture-mapped 3D surface. Blue squares depict the camera positions and orientations. The numbered flags indicate the positions of the GCP used for bundle adjustment (C).](image)

2.2. Processing of digital photographs and datasets
In this study, Agisoft Photoscan Professional software is used to process the geo-tagged images obtained from the quadcopter UAV. At first, the geo-tagged photographs are imported into the software and followed by photo alignment in which the accuracy is set to high with the pair pre-selection based on image GPS coordinates as stored in the Joint Photographic Experts Group Exchangeable Image File Format (JPEG-EXIF) headers. Then, feature matching is followed by a bundle block adjustment. Two different datasets are produced from the same amount of photographs: model without and with GCP. Next, dense geometry reconstruction is also set to high accuracy and there are 59 million points in the dense cloud. The final outcome is to export Digital Surface Model (DSM) and orthophoto based on the dense 3D geometry. A comparison of results between the two sets is discussed in the following section. Detailed description of the Photoscan workflow can be referred to the method established by Lucieer et al. [20] and Agisoft Photoscan User Manual [21].
The dense point cloud generated based on GCP is imported into the open-source software, CloudCompare, using the Facet plugin to extract the geological planes in the rock outcrop. There are two methods of extracting the discontinuities: Kd-Tree (KD) approach and Fast Marching (FM) approach with both methods implementing a least square fitting algorithm. Kd-tree approach divides the 3D point cloud recursively into small planar patches until the points fit the best-fitting plane given the Root Mean Square (RMS) threshold. These planar patches are then back clustered into bigger facets according to a co-planarity criterion. On the other hand, FM approach divides the 3D point cloud systematically into smaller patches and subsequently regroups them. Hence, all the patches will have similar size. After the meshes or facets are extracted, they can be classified by orientation (dip/dip direction) into single planes and plane families. A stereogram can be produced which is useful for rock slope stability analysis. Query can be done on the stereogram with the outcrop portion being selected. Lastly, the facets data can be exported as Comma-Separated-Variable (CSV) ASCII file or shapefiles for further analysis in other software. Figure 4 depicts the summary of the methodology of using facet plugin in cloudcompare to extract geological planes from 3D point clouds. Figure 5 summarizes the research methodology in the form of flowchart.

Figure 4. Flowchart of extraction of geological planes in CloudCompare using FACET plugin.

Figure 5. Flow chart of research methodology.
3. Results and Discussion

SfM photogrammetry has been carried out to map the 27700m² rock slope. The images are processed without and with GCPs to see if there is any significant difference between the two variables. Without GCPs, the images are aligned according to their own positions respectively since each photo is geo-referenced by the built-in GPS in the UAV device. On the other hand, with GCPs, the images are aligned accordingly to the coordinates obtained from RTK-GPS without considering the positions of the camera. From table 2, there is a significant reduction, nearly 80% in Root-Mean-Square Error (RMSE) if the images are aligned with GCP compared to images aligned without GCP. The total RMSE obtained for the case of with GCP is 21cm which is acceptable as the GPS instrument can only receive single frequency, L1 signal. Moreover, the RMSE for control scale bar is 12mm (Table 3). Hence, GCP plays a critical role in increasing the accuracy of the results and this method must be applied in conducting photogrammetry for data acquisition of the topography.

**Table 2.** Comparison of RMSE between bundle adjustment without GCPs and with GCPs.

| Bundle Adjustment | X error (m) | Y error (m) | Z error (m) | XY error (m) | Total error (m) |
|-------------------|-------------|-------------|-------------|--------------|-----------------|
| Without GCP       | 0.6932      | 0.5225      | 0.6292      | 0.8681       | 1.0721          |
| With GCP          | 0.1461      | 0.1047      | 0.1074      | 0.1797       | 0.2094          |

**Table 3.** RMSE of control scale bars.

| Label  | Distance (m) | Error (m)     |
|--------|--------------|---------------|
| P1_P2  | 7.4351       | -0.0048954    |
| P3_P4  | 36.9484      | -0.0115581    |
| P4_P5  | 20.9617      | -0.0182788    |
| P5_P6  | 42.337       | 0.0169887     |
| P9a_P10a | 5.5544    | 0.0094210     |
| P11_P12| 1.2714       | -0.0026419    |
| Total  |              | 0.0120832     |

**Figure 6.** DSM Without GCP (A) and With GCP (B).
Moreover, DSM for 3D model without and with GCPs are produced and shown in Figure 6a and 6b respectively. Graphs of elevation against distance are plotted in figure 7a and 7b respectively for two different lines where line 1 is from 100.145072, 6.429311 to 100.144928, 6.428640 and line 2 is from 100.144816, 6.429324 to 100.144413, 6.428721. Using the same coordinates for both DSM without and with GCPs, it can be clearly seen that there is a difference of nearly 10m elevation for both line 1 and line 2. This phenomenon indicates that GCPs will render better results in term of accuracy since it has undergo bundle adjustment optimization based on the global coordinates, followed by a dense geometry reconstruction. Without GCPs, the dense geometry reconstruction is based on the geo-tagged positions as recorded by the UAV on-board data logger. Figure 8 depicts the orthophoto with GCPs produced overlaying on the Google Earth image.

Figure 7. Comparison of elevation between data without and with GCPs in Line 1 (A) and Line 2 (B).

Figure 8. Orthophoto with GCP overlays on Google Earth Image (Google Earth Pro).
Figure 9. Facets extracted from 3D dense cloud using FACET plugin in CloudCompare. Top view (A) and Front view (B).

In CloudCompare, FACET plugin is 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 FM approach in plane segmentation, 3852 facets are produced and grouped according to their dip / dip direction. From figure 9a and 9b, it can be noticed that there are two major discontinuity sets: Set 1 (dark green) and Set 2 (dark blue). The mean dip/dip direction for Set 1 is 046°/169° whereas for Set 2, it is 044°/191°. The mean dip/dip direction for these two discontinuity sets is 044°/182° and its stereogram is depicted in figure 10. Cloudcompare renders a dip/dip direction of 044°/175° for the area circled in orange whereas manual measurement using geological compass, inclinometer and measuring tape gives a dip/dip direction of 046°/174°. There is a difference of up to 2° of dip angle and dip direction between the digital and compass measurement. Nevertheless, the result is within the tolerance limit since natural outcrop roughness contributes to the variability. This indicates that FACET plugin in CloudCompare can extract geological planes accurately based on its algorithm.

By observing figure 9b, the dominant discontinuity sets are dark green and dark blue. Normally, scanline methods are carried out at the bottom portion of the rock slope due to accessibility problem to the upper portion of the rock slope. From scanline method, dark green orientation is able to be measured only. Nonetheless, upper portion and lower portion of the rock slope are having different discontinuity sets with dark blue and dark green respectively. Hence, without obtaining data from the upper portion of the rock slope, the data collected merely based on the bottom portion cannot represent the entire rock slope. Using photogrammetry to obtain rock outcrop is a better approach in reducing bias and getting reliable results. 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 smoothed edge. Textures in the rock mass are not sharp and therefore results obtained will be inaccurate.
4. Conclusion
Structure from motion (SfM) is a cost and time effective method in acquiring rock slope data. It improves the quantity and quality of the data obtained compared to scanline survey. Images of the rock slope are captured by a camera mounted on the UAV. Accurate dense point cloud, orthophoto and DSM can be produced from images that go through the bundle adjustment with coordinate of GCPs obtained via RTK-GPS. Geological planes extracted from the high accuracy dense points cloud using FACET plugin in CloudCompare is reliable and accurate since it is similar to the data obtained manually. Two major discontinuity sets and random discontinuities are identified from the facets plane extraction. Therefore, the method proposed in this paper is useful; especially the orientations of the rock slope obtained can be an input for the rock slope stability analysis.

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