



## Applicability Assessments of Close-Range Photogrammetry for Rock Slope Face 3D Modelling

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**Abstract** – The digital single-lens reflex (DSLR) cameras have been widely accepted to use in rock slope face photogrammetry rather than the expensive metric camera used for aerial photogrammetry. 3D models generated from digital photogrammetry can approach those generated from terrestrial laser scanning in terms of scale and level of detail. It is cost-effective and has equipment portability. This paper presents and discusses the applicability of close-range digital photogrammetry to produce 3D models of rock slope faces. Five experiments of image capturing method were conducted to capture the photographs as the input data for processing. As a consideration, the appropriate baseline lengths to capture the slope face to get better results are around 1/6 to 1/8 of target distance. The exceptional quality of the 3D model from data processing is obtained using a strip method and convergent method with 80% overlapping in each photograph. A random camera position with different distances from the slope face can also generate a good 3D model; however, the entire target should be captured in each photograph. The accuracy of the models is generated by comparing the 3D models produced from photogrammetry with the 3D data obtained from a laser scanner. The accuracy of 3D models is entirely satisfactory, with the mean error range from 0.008 to 0.018 m.

**Keywords** – close-range photogrammetry, rock slope face, laser scanner, 3D model

### Introduction

The development of digital cameras and computerized mathematical solutions has provided a new stage in 3D imaging techniques (Fryer *et al.*, 2007). The usefulness of these techniques has been considered by many professions, including mining and geotechnical engineers. The basic concept of 3D imaging techniques is Photogrammetry.

Photogrammetry was widely used in the production of a topographic map, which then the products can be converted into three-dimension, creating a so-called Digital Terrain Model. However, the development of technology makes further application possible. It is known as close-range photogrammetry. “Close-range” refers to the object distances in the range of up to 100 m, for which the stereo cameras have been developed (Wolf, 1974; Kraus, 1993). Since the fast development of the computing system and with the help of complex mathematical algorithms, the use of amateur cameras or digital hand-held cameras has become possible in photogrammetric measurements.

Photogrammetry uses a series of photographs overlying one another to create 3D surfaces from which measurements are made (Haneberg, 2008). The close-range photogrammetry is the technique of using two-dimensional images to measure three-dimensional physical objects (Esmaili *et al.*, 2013). In recent years, the use of digital single-lens reflex (DSLR) cameras has been widely accepted to produce slope face photogrammetry rather than the expensive metric camera used for aerial photogrammetry. 3D models generated from digital photogrammetry can approach those generated from terrestrial laser scanning in terms of scale and level of detail. It is cost-effective and has equipment portability.

This paper aims to assess the applicability of close-range digital photogrammetry to produce 3D models of rock slope faces. The assessment is based on experiments on existing methods of capturing

photographs for photogrammetry. The image capturing techniques are then evaluated. Besides, the accuracy of the 3D model registration experiments is also computed.

### **Materials and Methods**

The object of this project is located approximately 15 km south of Kalgoorlie, Western Australia. It is a rock slope face in an abandoned quarry site with a fine geological feature. The lithology along the site is primarily mafic intrusive and granite. It is most likely a homogenous stratum that supports nearly vertical slopes. The nature of the discontinuities and the orientation are varied, and it is mainly jointing with some faults. The façade of the slope face can be seen in Figure 2.

Fieldwork presented in this paper contains several experiments of image capturing techniques for close-range digital photogrammetry and a laser scanning survey. A Canon EOS 450D digital camera with 28, 36, and 50 mm focal length lens was used to capture photographs of the slope face (Figure 1a). Laser scanning was obtained using an MDL Void Laser Scanner VS150 (Figure1b).



**Figure 1.** Field Equipment. (a) Canon EOS 350D digital camera; (b) MDL void laser scanner VS150; (c) Leica TS150 total station; (d) Garmin T60 hand-held GPS



**Figure 2.** The rock face of the slope

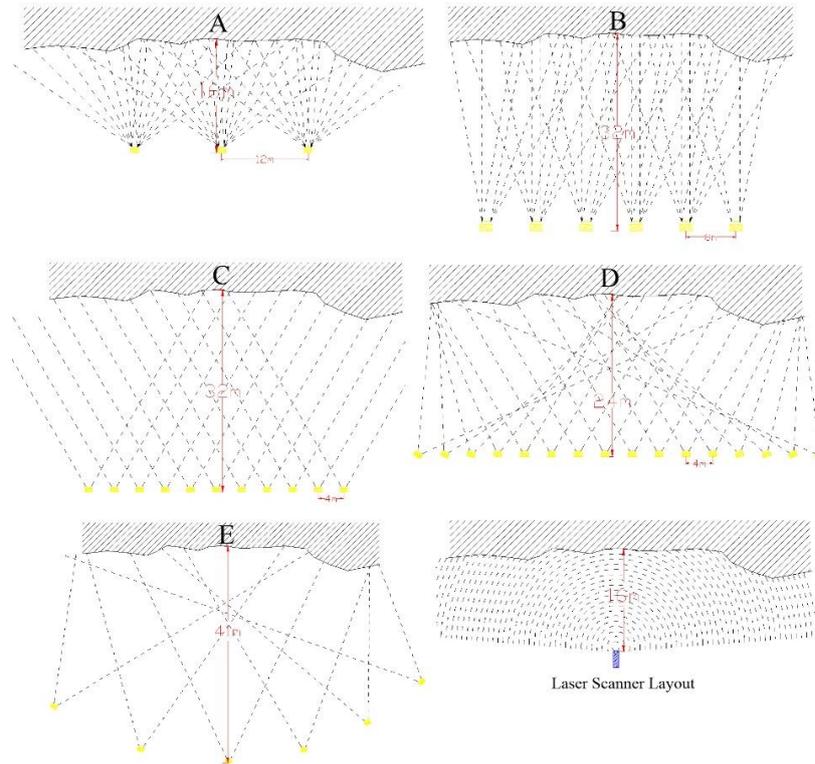
### **Image Capturing Method**

The most commonly used methods to capture images for photogrammetry are proposed by Somervuori and Lamberg (2009). The first one is a strip model. The strip method is used in cases where the

camera should be relatively closed to target. The second method is the image fans. In cases where the camera can be moved relatively far away from the goal, the image fans can be used. The last one is an independent convergent model method which combines both fans and strip method. Each method was used to capture images of slope face with different configurations. Several experiments were conducted at the site; however, only five experiments will be discussed, which represent the various configurations of the methods. Table 1 provides details of the five trials that were conducted in this study using close-range digital photogrammetry. The layouts of each experiment are shown in Figure 3.

**Table 1.** Approaches used for the experiments

<b>Experiment A</b>	A 50 mm fixed focal lens was used for this experiment. The photographs were captured in landscape mode. Consequently, the facade of the slope face cannot be captured from top to bottom, which results in taking several photographs in one session with vertical increments. The pictures were taken using a fan model layout from three locations for this configuration. Each camera location has 12 meters spacing from each other. The distance between the camera positions and the slope face is 16 meters. The average camera lines of sight were perpendicular to the slope face being captured. A tripod is used for the camera, and the height above the ground surface is measured using the measuring tape. The camera height for this configuration is 1.5 meters.
<b>Experiment B</b>	Fan model layout is used, but it is taken from six camera positions. The distance between the two camera locations is 8 meters, and the distance between the camera locations and the slope face is approximately 16 meters. Therefore, the baseline length is $\frac{1}{4}$ of the target distance. A tripod is also used with this configuration, and the measured height of the camera above the ground is 1.5 meters. The camera is mounted with a fixed 50 mm focal length. The shooting mode is changed to portrait mode, which can cover the top and the bottom of the slope face within this distance. The total number of photographs that were captured with this configuration is more than 60 photographs.
<b>Experiment C</b>	This experiment is using a strip method where the photographs are taken each in eleven camera positions. The distance between the camera locations and the slope face is 32 meters, and the distance between the two camera positions is 4 meters. This allows a $\frac{1}{8}$ ratio between the baseline length and the target distance. The camera line of sight is perpendicular to the slope face being captured. The tripod is still used with the same 1.5 meters height above the ground. The lens that is used in this experiment is an 18-55 mm zoom lens. However, for this purpose, the focal lens is locked at 28 mm focal length. This allows a wider camera angle to capture the target slope face. Therefore, the overlapping photographs captured from each camera position can be more than 50% within the 32 meters target distance. There were eleven photographs captured using the strip model layout.
<b>Experiment D</b>	This experiment is using a modified strip and convergent method. The target is to include the entire slope face object in each photograph that is taken in each camera position. Unlike the former strip method, where the camera line of sight is perpendicular to the slope face, this method is using different angles of camera line of sight to comprise the entire slope face into each photograph. To tolerate this configuration, a 28 mm focal length is used. Hence, the camera angle is sufficient to capture mainly the entire slope face in each photograph. As a result, the overlapping object with this configuration is more than 80%. The distance between the two camera locations is 4 meters, and the distance between the camera locations and the slope face is approximately 24 meters. It means the ratio between the baseline length and the target distance is $\frac{1}{6}$ . The height of the camera position above the ground is maintained at the same height of 1.5 meters for the entire process using a tripod.
<b>Experiment E</b>	This experiment is using a convergent method with random camera positions. There are six camera positions to capture the target slope face. The camera position is scattered along the bench or slope face to capture the entire slope face from different angles. The farthest distance between the camera positions to the slope face is 41 meters. An 18-55 mm zoom lens is used for this configuration with a 36 mm focal lens locked for an entire photoshoot. With this focal length, the camera angle allows the overlapping images between photographs of more than 80%. The tripod is still used with this method with the same 1.5 meters camera height from the ground.



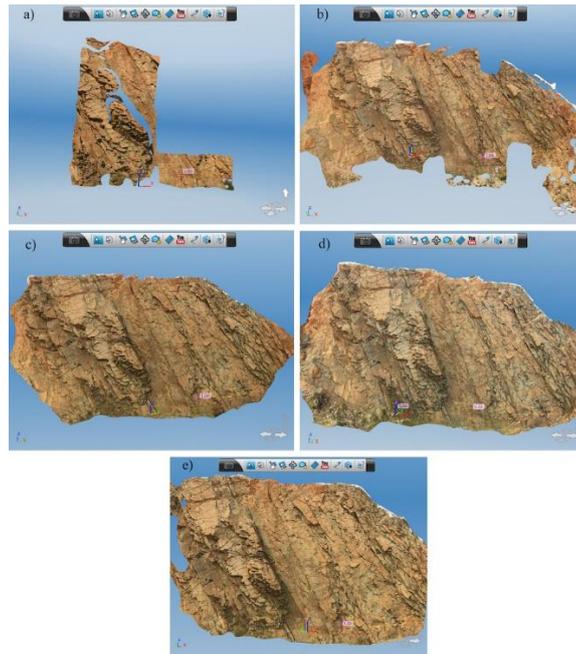
**Figure 3.** Image capturing methods. (a) Configuration of experiment A; (b) Configuration of experiment B; (c) Configuration of experiment C; (d) Configuration of experiment D; (e) Configuration of experiment E; (f) Configuration of the laser scanner

### 3D Model of Slope Face

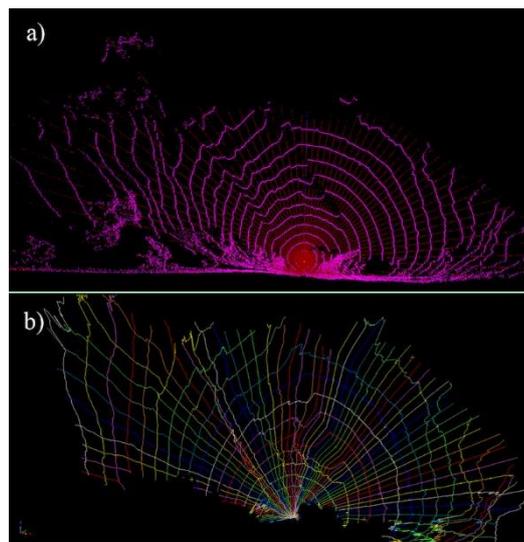
All the photographs captured from each method are processed in photogrammetry software. The software used the series of photographs as the input to create the 3D model (Figure 4). To use the 3D model meshes in any CAD software, the results need to be converted into the CAD's recognized file type. This project utilizes additional software called Meshlab to convert the file.

The data from the laser scanner is processed using MDL software that is included as one package with the MDL's Void Laser Scanner VS150. A result is a group of laser point clouds in 3D. The data can be exported to any CAD software such as Autocad and Surpac.

For this study, the data is exported to Surpac, well-known mining software, as a string file. Since the laser scanner is used initially to capture voids, it scans all the terrain in 360 degrees. Therefore, the entire object around the laser scanner is achieved. The point cloud data is then edited; thus, it only displays the required 3D object, which is the rock face of the slope. Figure 5 shows the end result of the point cloud in Autocad and 3D string in Surpac.



**Figure 4.** 3D slope face model. (a) Result of experiment A (Model A); (b) Result of experiment B (Model B); (c) Result of experiment C (Model C); (d) Result of experiment D (Model D); (e) Result of experiment E (Model E)



**Figure 5.** 3D point cloud in Autocad (a) and 3D string in Surpac (b)

## Results

### 3D Model Quality Analysis

All the experiments presented are using a different configuration. The various configuration includes some varieties in the distance between the camera position and the slope face, the distance between each camera position, the different on the focal length of the lens and the various on the shooting mode (Table 1).

The 3D model produced using experiment A is not satisfactory; most of the objects are missing. The 3D surface of the slope is not created successfully from this experiment. Experiment B, however, produced a comparatively good result than the first experiment, although some target parts are missing from the 3D surface.

The best results are shown by experiments C, D, and E, which use the strip method, the strip-convergent method, and convergent method, respectively. It means that the configurations of each experiment (C, D, and E) are adequate for capturing the slope face and processing.

The experiments C and D are using a lens with 28mm focal length, and experiment E is using a 36mm focal length. This allows capture of the entire slope face using a practical number of photographs. As recommended by Sturzenegger and Stead (2009), the lenses with focal lengths between 20mm to 50mm are sufficient for rock-cut. Although experiments A and B are using 50mm focal length, the distance between camera location and the slope face is relatively short, and the slope face cannot be captured entirely. Therefore, the 3D models are not generated correctly. It can be managed by increasing the distance; however, it will degrade the quality of photographs.

### 3D Model Accuracy Evaluation

The accuracy of 3D positioning in close-range photogrammetry is essential to obtain high-quality 3D models. Several publications have proposed and evaluated different approaches to providing accurate 3D models. Ohnishi *et al.* (2006) have performed a test to verify the precision and accuracy of a measurement system that adopts a numerical solution obtained from the Moore-Penrose generalized inverse matrix. Sturzenegger and Stead (2009) have used several approaches to the image registration process to get the final accuracy of 3D models. Also, Jiandong, Liyan, and Xiaoyu (2009) have investigated the way to accurately locate the 3D target point from a small set of images taken with a hand-held digital camera.

The accuracy of the 3D models is obtained by using two methods. The first method is comparing the length of four control lines on the slope face that is measured manually with the extent of those lines on the 3D models. The second method is overlaying each 3D model with 3D data from the laser scanner and comparing the position of two reference points between them.

There are only three models used to compare the length of control lines, which are the models generated from experiments C, D, and E. The results are shown in Table 2.

**Table 2.** The accuracy of the 3D model relative to the measurement of the actual length of control lines

	Control Lines	True length (m)	Model measurement (m)	Difference (m)	Average difference (m)
<b>Model C</b>	Line 1	1.0	1.012	0.012	0.0115
	Line 2	1.0	1.011	0.011	
	Line 3	0.5	0.510	0.010	
	Line 4	0.5	0.513	0.013	
<b>Model D</b>	Line 1	1.0	0.989	0.011	0.0105
	Line 2	1.0	0.989	0.011	
	Line 3	0.5	0.490	0.010	
	Line 4	0.5	0.490	0.010	
<b>Model E</b>	Line 1	1.0	0.989	0.011	0.0110
	Line 2	1.0	0.990	0.010	
	Line 3	0.5	0.489	0.011	
	Line 4	0.5	0.488	0.012	

The accuracy of models generated by overlaying each model is achieved by calculating the mean error of the control point positions in Surpac (Figure 6). The results are shown in Table 3.

**Table 3.** The accuracy of a 3D model derived from overlaying with laser scanner data

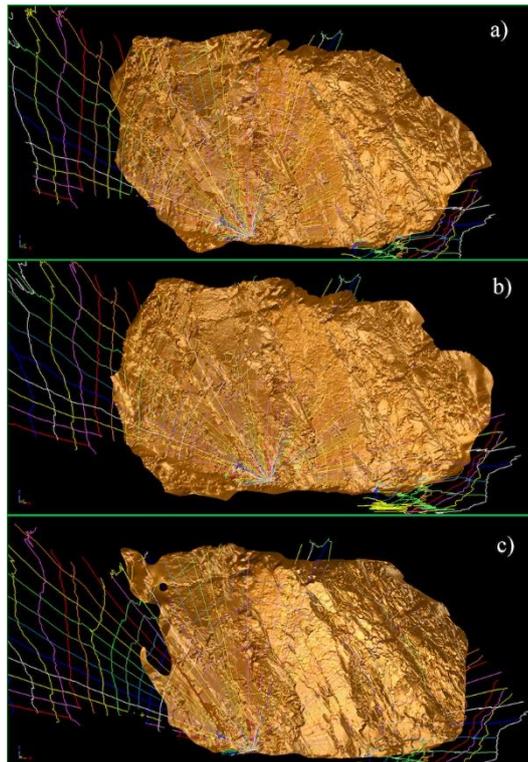
	Mean Error (m)		
	X	Y	Z
<b>Model C</b>	0.010	0.012	0.010
<b>Model D</b>	0.008	0.010	0.011
<b>Model E</b>	0.015	0.018	0.013

### Discussion

Based on the experiment's results, all three models have good accuracy that ranges from 0.0105 m to 0.0115 m. The highest accuracy is achieved by the configuration of Experiment D with the lowest mean error when compared to the laser scanner (0.008 m). Model C is slightly less accurate than the Model E in terms of length measurement. However, Model C is more accurate when the models compared to the laser

scanner. According to Somervuori and Lamberg (2009), the accuracy of the 3D model results relies on working distance, camera lenses used, and also the distance between camera stations. The accuracy is up to 15 microns when the target's distance is 150 mm and 0.1 m when the distance is 3 km. The results of the case study detailed by Sturzenegger and Stread (2009) have shown that the accuracy can be improved by adding surveyed control points in the field of view other than the working distance, camera lenses used and also the distance between camera stations, which was proposed by Somervuori and Lamberg (2009).

In terms of the detail of the texture, the photogrammetry can give more detail than the laser scanner. At some terrain, the laser scanner cannot detect the plane because the line-of-sight of the camera is directed upwards at an angle steeper than the plane. The use of a camera or laser scanner does not influence the results significantly; therefore, using a camera is adequate to acquire high-quality results.



**Figure 6.** The overlays between 123D Catch slope face 3D models and laser scanner 3D strings in Surpac.

(a) Model C; (b) Model D; (c) Model E

## Conclusions

The experiments conducted in this paper show that the use of a DSLR camera with a photogrammetry technique is applicable to produce the 3D model of slope face. From five experiments of image capturing methods, the first experiment (Experiment A) does not give a good result, the second experiment (Experiment B) can generate a fine 3D model but has some missing facades, and the last three experiments (experiment C, D, and E) result in excellent quality of 3D models. Based on the experiments, the appropriate baseline lengths to capture the slope face to get better result are around  $1/6$  to  $1/8$  of target distance (Experiment C and D) and a fine quality of 3D model is obtained using strip method and convergent method with 80% overlapping in each photograph (experiment C, D, and E). Random camera positions with different distances from the slope face (experiment E) can also generate a good 3D model; however, the entire target should be captured in each photograph. Furthermore, the accuracy of 3D models is satisfactory, with the mean error range from 0.008 to 0.018 m. Therefore, it is recommended to use strip method and convergent method with image capture baseline length around  $1/6$  to  $1/8$  of target distance and 80% overlap in each image, as an image capturing technique, for slope face photogrammetry to obtain high accuracy of data.

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