A Conceptual Study for Development of 3D Rock Fragmentation Analysis System with Stereo-photogrammetry Technologies

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Abstract

One of the most important aspects of mine blasting is accomplishing proper rock fragmentation to optimise not only blasting operation itself but also the entire mine to mill processes. As improper fragmentations, i.e., oversizes and fines, extremely deteriorate overall mining processes, its in-depth analysis is essentially required. In the area of rock fragmentation measurement, 2D photo based fragmentation measurement systems have been primarily used for nearly three decades. Meanwhile, its disadvantages of inaccuracy and inconvenience have been assiduously raised. In this study, in order to overcome the limitations of current 2D based rock fragmentation measurement methods, in development of 3D rock fragmentation analysis system using stereo-photogrammetry technologies has been established. The advanced stereo-photogrammetry technologies within the proposed system will facilitate accurate detection of rock fragments without any scalier and further requirement of excessive manual editing. Furthermore, the representative fragmentation of a whole blasting shot can be promptly analysed by generating 3D digital model of the entire blasted rock piles in the proposed system.

Keywords: Mine blasting, Rock Fragmentation, stereo-photogrammetry

1 Introduction

Since the first industrial blasting used to excavate rock in 1627 in Hungary (Buffington, 2000), drilling and blasting has been rapidly prevailed into mining industry due to its high economic efficiency. Meanwhile, the technical features of blasting engineering have been evolved significantly through numerous breakthroughs of introducing new generations of explosives with theoretical and empirical developments. Indeed, the modern standard rock blasting methods in both surface and underground are recognised as the most effective rock excavation methods.

In mining industry, the main goal of rock blasting is to break the targeted rock into favourable sizes on its own purpose without damaging secured circumjacent objects. In other words, the efficiency of a blasting can be maximised by minimising unwanted fines and oversizes that directly and/or indirectly affect the downstream of mine to mill processes. In spite of indefatigable endeavours of mining engineers, achieving favourable size distribution is one of the challenging task in rock blasting due to the complex physio-mechanical features of rock and their intricate responses to the dynamic blasting loads. Nevertheless, the favourable size distribution can be achieved by executing a well-established blasting reconciliation system that investigating fragmentation and back-analysis with its own blasting design.

The most certain rock fragments measurement methods are sieving and screening which directly measure sizes. They are still utilised in the laboratory scale test but limitedly applied in field test due to financial and physical limitations. The initial photo-based blasted rock pile fragmentation measurement methods in mining have been introduced in 1980s (Nie & Rustan, 1987; Singh, 1983). Soon after, Maerz et al. (1987) introduced a digital photo based fragmentation analysis method that mounded an edge detection algorithm. Since then, many similar systems have been developed and exclusively utilised in mining industry nearly three decades. Some of representative 2D photo based fragmentation measurement systems have been tabulated in Table 1.

Table 1 Lists of representative 2D photo based fragmentation measurement systems. Modified after Sudhakar et al. (2006)

Developer	System
Maerz et al. (1987)	WipFrag
Cheimanoff et al. (1993)	Fragscan
Kemeny (1995)	Split
Dahlhielm (1996)	IPACS
Havermann and Vogt (1996)	TUCIPS
Schleifer and Tessier (1996)	FRAGSCAN
Downs and Kettunen (1996)	CIAS
Kleine and Cameron (1996)	Goldsize
Chung and Noy (1996)	PowerSieve
Raina et al. (2002)	FRAGALYST

Those methods in Table 1 have been widely employed for rock fragmentation measurement due to its ability of outputting quantitative result of size distributions without much hardships. Meanwhile, the disadvantages of 2D photo based fragmentation measurement systems have been raised consistently in the following aspects. Firstly, the size measurement is somewhat unrealistic. The calculated particle sizes are diameters of spheres that been modelled based on the projected area of each particles appear on a photo (Bedair et al., 1996). Secondly, one of challenging difficulty is the error of boundary delineation or particle segmentation that frequently occur primarily due to low resolution of photo, variations of lighting, colour, and rock texture. Such errors result in massive manual editing. Thirdly, those 2D photo based fragment measurement systems always require scalers on blasted rock muckpile which can easily cause safety problem. Laser pointer is often used as a scaling tool but the cost effectiveness should be considered. Frothy, as the particle size measurement is based on 2D photo, overlapped particles are unable to reliably identified (Onederra et al., 2015). Lastly, it is difficult to get an overall fragment size distribution of a shot due to size limitation of photos. For instance of a normal open pit mine, tens of meters of bench is blasted in one shot. To obtain an overall fragment size distribution of the shot with 2D photo based fragmentation measurement system, it is required to analysis dozens of photos taken alongside of the blasted muckpile.

To overcome the disadvantages of 2D photo based fragmentation measurement system, recently few attempts have been conducted to develop 3D fragmentation analysis. Han and Song (2014) applied stereo-photogrammetry to analysis blast fragmentation. A 3D modelling program (PhotoModeler) was used to build 3D digital model of a heap of rock blocks to calculate equivalent diameters of rock blocks under an assumption of that the shape of rock blocks are all perfect spheres. Regardless of the assumption, the study showed a superior result of stereo-photogrammetry than 2D photo based fragmentation measurement systems. Onederra et al. (2015) applied 3D laser scanning to measure blast fragmentation. One of advantages of applying the 3D laser scanning to rock fragment measurement is its accurate delineation ability without influence of lights or colours. However, application of 3D laser scanning tool could not answered most of demands and the cost effectiveness and field applicability of the method are still in doubt. Liu et al. (2015) introduced a new tool to analysis rock fragmentation named 'PortaMetrics'. One merit of the tool is that it does not require referencing scalers as the scaling information is provided from a built in stereo camera. Other than that, the fundamental function and process of participle size analysis are analogous to existing 2D photo based fragmentation measurement systems.

This paper will demonstrate a new concept of rock fragmentation analysis adopting stereo-photogrammetry technologies. The remainder of the manuscript is organised as follows Next section will provide brief overview of the stereo-photogrammetry technologies. The concept of stereo-photogrammetry implication to rock fragmentation measurement will be illuminated in Section 3. Section 4 presents detailed discussions and Section 5 concludes the research with emphasising key advancing features of the new rock fragmentation measurement method using stereo-photogrammetry technologies.

2 Stereo-photogrammetry

Stereo-photogrammetry is one of photogrammetric methods that construct 3D geometry of an object by processing multiple 2D images of the object. In other word, the process of stereo-photogrammetry is simply converting 2D image coordinates (x, y) in multiple photographs into 3D coordinates (X, Y, Z) as illustrated in Fig. 1. As a brief explanation of constructing 3D geometry of an object, imagine that the projection centre points (Camera stations: C_1 and C_2) and directions of the two imaging rays to the entity points (m_1 and m_2) are known. Then the object point (M_1) in the 3D imaginary coordinates would be represented by finding intersections of two matching entity points in photo 1 and 2 which is called 'image matching'.

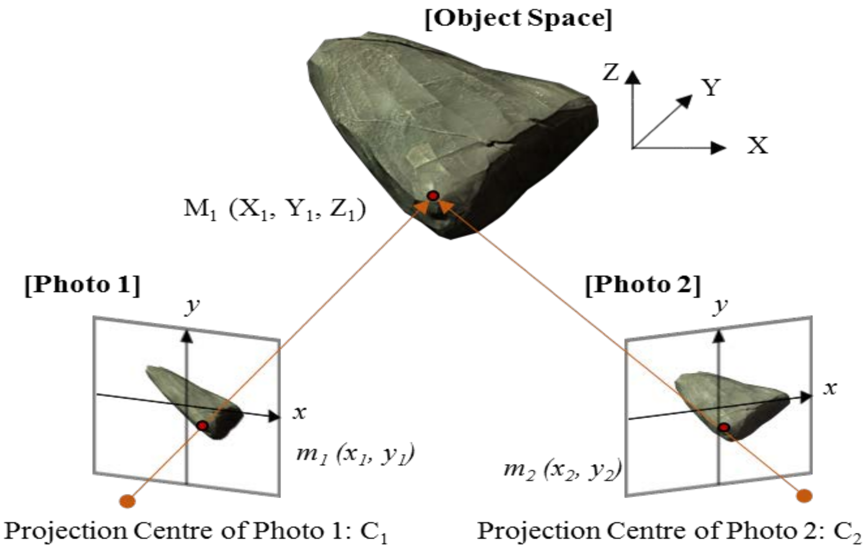


Fig. 1. An example of photogrammetric system

As the increasing application range of stereo-photogrammetry and rapid technical improvements in the areas of computer and digital-photography sciences over the last years, numerous 3D reconstruction algorithms have been introduced. Fig. 2 demonstrates a typical order of reconstructing 3D model. As different algorithms would be used in each stage but the prime procedures would be: data acquisition, data handling for each image, reconstruct 3D geometry, and the reconstruction of object texture (Furukawa & Hernández, 2015).

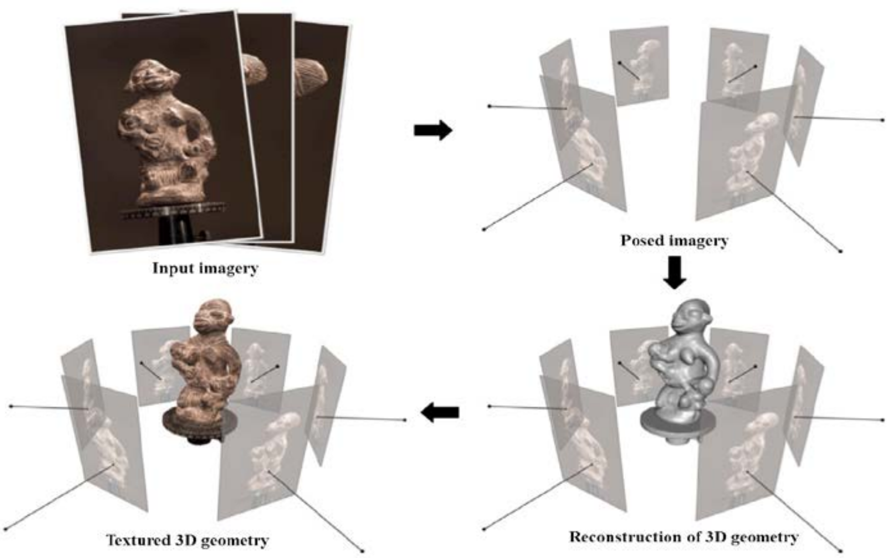


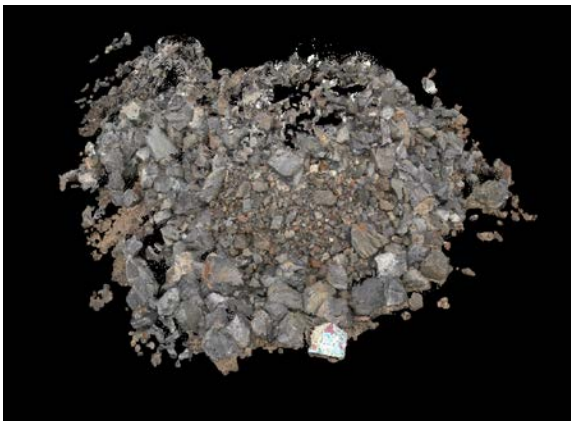
Fig. 2. Example of a multi-view stereo pipeline (Furukawa & Hernández, 2015)

3 Demonstration of fragmentation measurement using photogrammetry

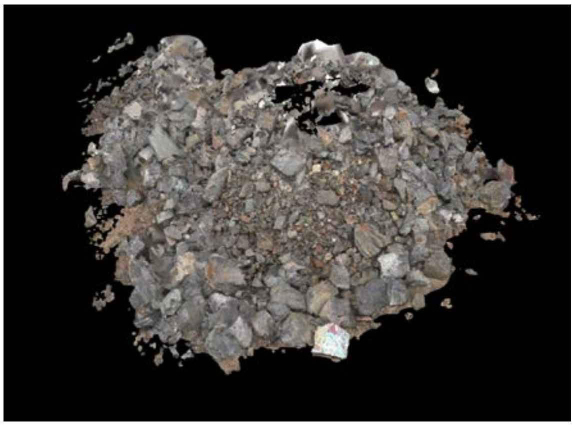
Blasted fragmentation measurement demonstration was done for a blasted rock pile in a quarry in Japan. Sparse point clouds of the blasted rock pile was generated through Structure from Motion (SfM) technology which is one of the most popular and actively developing methods to reconstruct 3D point cloud from multiple-view images by estimating 3D position of the feature points and pose of the capturing cameras using a factorization method (Fig. 3 (a) and (b)). Then, a dense point clouds model and 3D model of the muckpile (Fig. 3 (c) and (d)) were reconstructed applying Patch based Multi View Stereo (PMVS) method (Furukawa & Ponce, 2010) and Poisson Surface Reconstruction (PSR) (Kazhdan et al., 2006).

(a) Multi-view images

(b) Sparse point cloud



(c) Dense point cloud



(d) Reconstrcted 3D model

Fig. 3. Processes of constructing 3D muckpile model applying SfM, PMVS, and PSR

In the reconstructed 3D dense point clouds of the muckpile, each rock particle should be clearly distinguished from each other to measure sizes of them. In here, Supervoxels method (Papon et al., 2013) has been applied to cluster each particles and the clustered rock particles were fitted in bounding boxes to measure the size of them. The results of Supervoxels clustering and bounding box fitting have been illustrated in Fig. 4 and 5.

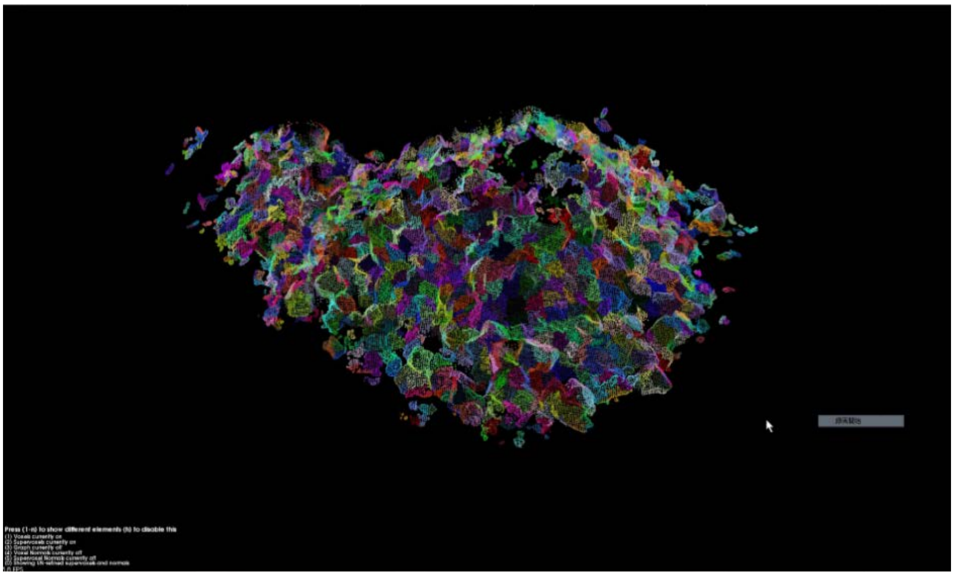


Fig. 4. Supervoxels clustering results of the rock pile.

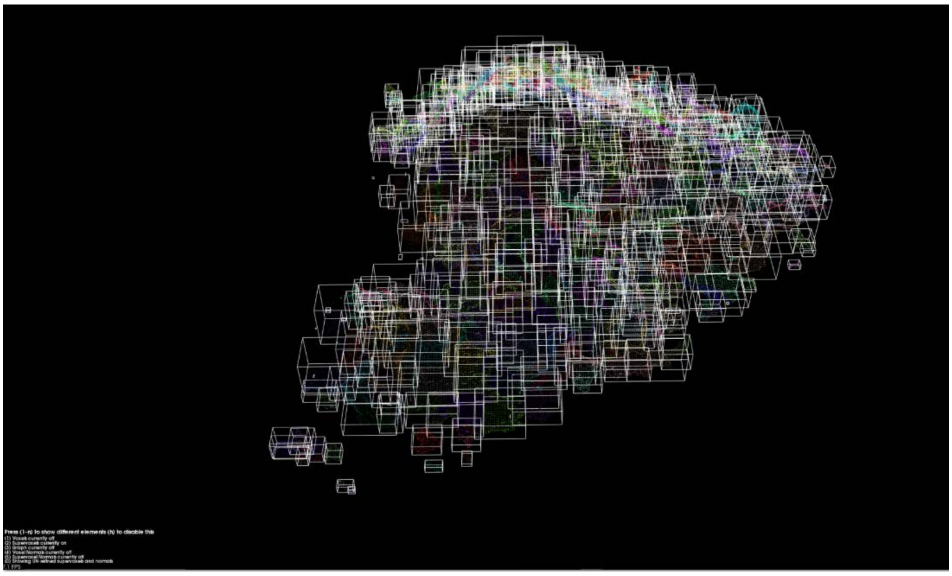


Fig. 5. Bounding box fitting on clustered rock particles

4 Results and Discussions

Size regularisation of rock particles in mining has been relied on the diameter of equivalent circle or sphere of irregular shape rock particles. The reliability of measuring equivalent diameter of rock particles has been generally acknowledged as it gives somewhat similar results with the conventional sieving and screening methods. However, they both intrinsically ignore the irregular shape of rock particles. In the introducing 3D rock fragmentation analysis system, the size of rock particles could be calculated in several different ways. For instance, sizes and percentage of accumulate rock particles in the demonstration have been extracted with 'max area' and 'volume' of each bounding box which are illustrated in Figure 6 and 7.

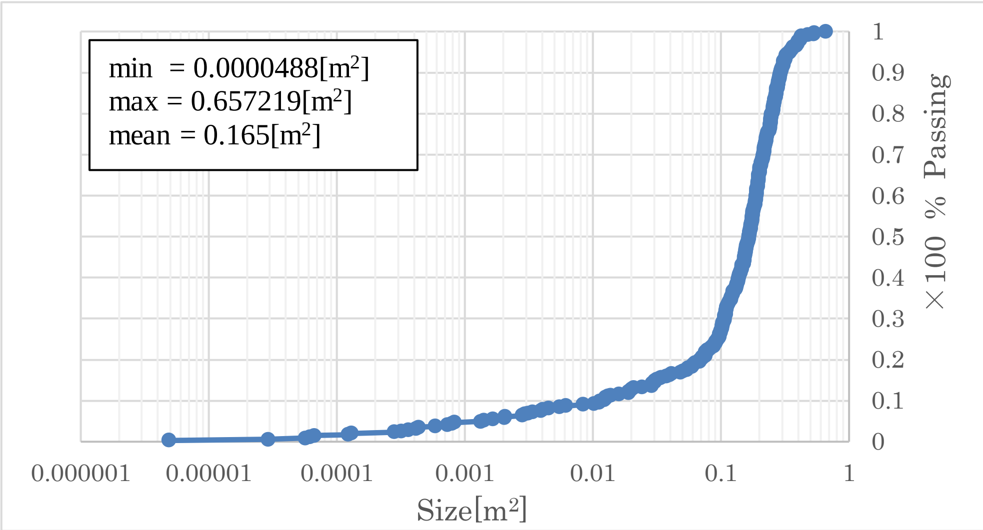


Fig. 6. Accumulated fragments expressed in max area of bounding boxes

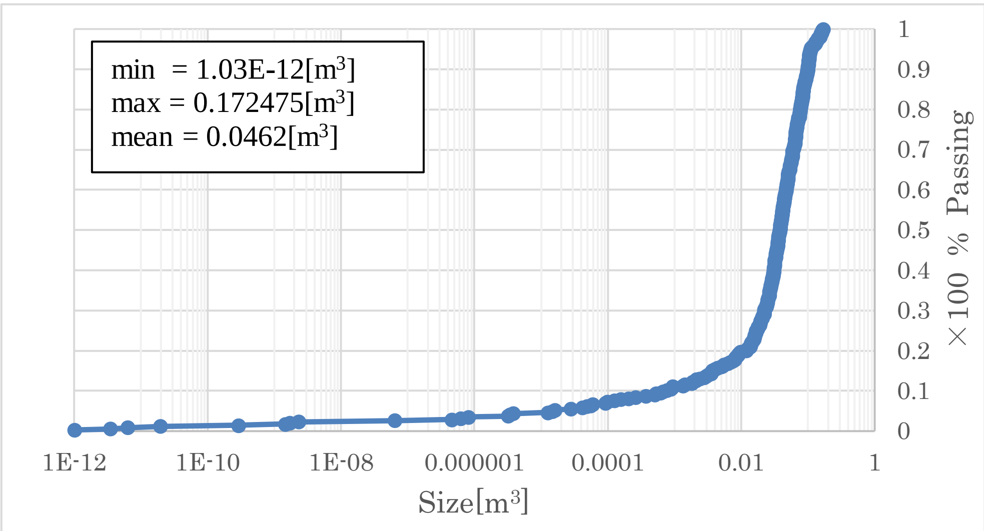


Fig. 7. Accumulated fragments expressed in volume of bounding boxes

As a conceptual study, the results show possibilities of adopting new units for size regularisation of irregular shape rock particles although it was roughly demonstrated in max area and volume of bounding boxes of rock particles. Through the demonstration, the most impressive advantages of the proposed 3D rock fragmentation measurement system can be:

(i) Auto scaling as acquiring scale information through GPS and/or other indirect methods.
(ii) One pass analysis to evaluate one whole blast as capturing 3D model of whole muckpile.
(iii) Low effects from overlapped particle as constructing 3D muckpile.
(iv) Much high reliability on irregular particle size measurements than traditional fragmentation measurement systems that only relied on the equivalent diameter.
(v) Quick and easy processes to analyse.

5 Conclusions

Fragmentation measurement system is mightily important in term of mine production management that facilitates a reliable blasting reconciliation to maximise productivity of the mine. Mining industry has been relied on conventional 2D photo based fragmentation measurement systems even though the technical disadvantages of the systems have been assiduously raised. To overcome all the difficulties of the conventional fragmentation measurement systems, a new concept of 3D fragmentation measurement system adopting the state of the art stereo-photogrammetry technologies has been introduced. The proposed system is expected to surmount the most of the difficulties that 2D photo based fragmentation measurement systems have been facing by extracting size information of rock particles by constructing 3D digital model. The presented demonstration herein is a field scale case conceptual study and the proposed system is under development to build a field applicable 3D fragmentation measurement system.

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