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Statistical estimation of blast fragmentation by applying stereophotogrammetry to block piles

Jeong-Hun Han, Jae-Joon Song *

Department of Energy Systems Engineering, Seoul National University, 599 Gwanak-ro, Gwanak-gu, Seoul 151-744, Republic of Korea

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ABSTRACT

Stereophotogrammetry is the technique to extract the spatial information of an object by constructing a stereo-image from two or more photos. Additional information about the geometrical features of an object can be obtained with stereophotogrammetry than with 2D image processing techniques. In this study, stereophotogrammetry based on 3D modeling was used for the analysis of the surface blocks, and the information on the surface blocks in muckpile was used as the input parameter for the statistical estimation of blasted blocks. Monte Carlo simulation and Latin hypercube sampling were used as the statistical estimation methods for the blasted blocks. In the laboratory experiments, results with stereophotogrammetry and 2D image processing technique were compared with the physical measurements using a water tank. Finally, the applicability of stereophotogrammetry and the statistical estimation methods to the analysis of blast fragmentation was estimated through the field experiments.

1. Introduction

Blast fragmentation analysis is the basic index for evaluating the efficiency of blast design and productivity. In rock engineering, computer software has been applied to analyzing the size distribution of the rock blocks, i.e., blast fragmentation analysis. Split Desktop, WipFrag, FragScan and GoldSize are the most popular software packages based on 2D image processing for performing the size distribution analysis of the rock blocks. These 2D image processing software packages and techniques have been used in research [1–9]. Such 2D image processing, however, was reported to overestimate the mean fragment size by approximately 50–100% of the sieve value [10].

More accurate information regarding the objects can be obtained by using stereophotogrammetry [11,12], which is the technique that extracts information by using a stereo-image (3D vision). Since the work of Hagan [13], this technique has been widely used in the rock mechanics field in applications, such as discontinuity measurement and analysis [14–17], modeling [18,19] and monitoring [20,21]. Regarding the blast fragmentation analysis with images, Van Aswegen and Cunningham [22] introduced the estimation of fragmentation by means of standard photographs for the first time. A stereovision system was applied to the analysis of blast fragmentation. A 3D laser scanner was used to measure the total volume of the blasted muckpile before and after the blast [23], and a 3D laser scanner and segmentation algorithm were used to analyze the blast fragmentation [24,25]. Han and Song [26] used stereophotogrammetry for blast fragmentation analysis. According to the previous study of Han and Song, the analyzed results from the stereophotogrammetry system introduced more accurate results than those from the 2D image processing system.

The economically significant sizes of blast fragments can be usually classified as oversize, mid-range and fines as follows [27].

- *Oversize*: The boulder size above which secondary breaking is necessary before further handling. In underground mines this can be as little as 300 mm, while in opencast mines it is seldom defined as greater than 1000 mm.
- *Mid-range*: Those fragment sizes that have significant, but not terminal importance for handling and the ability to achieve premium pricing.
- *Fines*: The particle size below which the product can either not be sold, or becomes difficult to handle, due to flow or other properties. A common minimum size of fines for coal or dolomite is 6 mm, but in gold ores, this size may be as small as 1 mm.

Especially in production blasting, secondary breaking is necessary when the blasted rocks are too large, i.e., oversize, which is an important characteristic for the design of loading and transportation systems [28,29]. The efficiency and cost for crushing can

* Corresponding author. Tel.: +82 2 880 9043; fax: +82 2 871 8938.
E-mail address: songjj@snu.ac.kr (J.-J. Song).

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be improved by eliminating oversize boulders [7]. The proposed method of this study was tested for oversize and mid-range blast fragments. This study proposes the statistical estimation method for blast fragmentation analysis of samples from the muckpile. The information of surface blocks in the muckpile was considered to be that of the samples, which was analyzed using stereophotogrammetry. The applicability of this combined method was determined through laboratory and field experiments.

2. Apparatus and software

2.1. Camera and lens

A Nikon D200 camera, which is digital single-lens reflex camera and has approximately 10 million picture elements, was used. Small size images (1936 × 1296 pixels) were used in 2D image processing due to the constraint of the program that was used in this study, while large size images (3872 × 2592 pixels) were used in stereophotogrammetry. The camera lens was a Nikon AF-S DX 18–70 mm f/3.5–4.5 G IF-ED, which is a standard lens and has a picture angle of 76°–22°50′.

2.2. Split Desktop

Split Desktop, which is based on 2D image processing, is one of the most popular software packages for the blast fragmentation analysis. Split Desktop uses images captured with an object that is used as a scaling parameter. In this study, a basketball was used as a scaling parameter. After the scaling process, images are delineated in two steps. First, in a step called Auto-Delineation, the software delineates images automatically with an image filter. In the next step, called manual editing, the image from the step of auto-delineation is delineated by the users. Through computing the size, the size distribution of the rock blocks can be obtained as the final output. In the step of manual editing, care should be taken because often the mistakes that either several small blocks merge into one large block or one large block becomes divided into several small blocks occur [7,9].

2.3. PhotoModeler scanner

PhotoModeler scanner is a 3D modeling software. Although it is not software specially designed for the blast fragmentation analysis, more geometrical features of an object can be obtained using the software. The software uses a stereo-image with targets placed around objects. The targets are for scaling and referencing. After the distortion of camera and lens is corrected, the determination of the relative location between the images is performed in a step called referencing. In the next step, scaling and 3D modeling are processed, and finally the volume of an object is analyzed. Fig. 1 shows the flowcharts of each of these analysis systems.

3. Statistical analysis

3.1. Assumptions

The assumptions applied to this study are as follows. Firstly, very rock block is assumed to be from the same site; therefore, each rock block has the same unit weight. With this assumption, the value of passing in the size distribution curve can be calculated easily using the volume ratio:

$$m = \gamma V, \quad Passing(\%) = \frac{m_x}{m_{total}} = \frac{\gamma V_x}{\gamma V_{total}} = \frac{V_x}{V_{total}} \times 100 \tag{1}$$

where m_x, V_x and γ are the cumulative mass, volume at x, and unit weight of rock, respectively.

Secondly, every rock block is assumed to be a perfect circle in 2D image processing, Split Desktop, and a perfect sphere in stereophotogrammetry, PhotoModeler scanner. Therefore, the equivalent diameter of a rock block can be calculated using the area formula of a circle and the volume formula of a sphere, as given by

$$D = \sqrt{\frac{4A}{\pi}} \tag{2}$$

$$D = 2 \times \sqrt[3]{\frac{3V}{4\pi}} \tag{3}$$

where D, A and V are the diameter, area and volume, respectively.

3.2. Procedure

The purpose of this study is the statistical estimation of blast fragmentation using samples from the entire muckpile. Monte Carlo simulation and Latin hypercube sampling were used as the statistical estimation methods for the blast fragmentation analysis. Monte Carlo simulation is the method to solve an uncertain problem statistically using random numbers and probability [30,31]. In Latin hypercube sampling method developed by McKay [32] in 1979, the numbers are generated randomly but distributed uniformly within the analysis range, while numbers in Monte Carlo simulation are generated randomly only. These statistical estimation methods have been widely used in rock mechanics due to the uncertainty of rock mass behavior [33–36]. In this study, the probability range was divided equally into 10 sections in Latin hypercube sampling. These statistical methods require the use of an input model describing the target of the estimation. The information of the surface blocks that could be identified intuitively and easily in a muckpile was used as the information of the input model. An individual surface block in muckpile was modeled in three dimensions, and its volume and diameter were analyzed. The statistical analysis performed in this study is as follows. First, a probability density function (PDF) is determined so that it fits best to the size distribution of the surface blocks through the frequency count analysis. In the next step, the cumulative distribution function (CDF), which has the horizontal axis of diameter and the vertical axis of probability, is determined

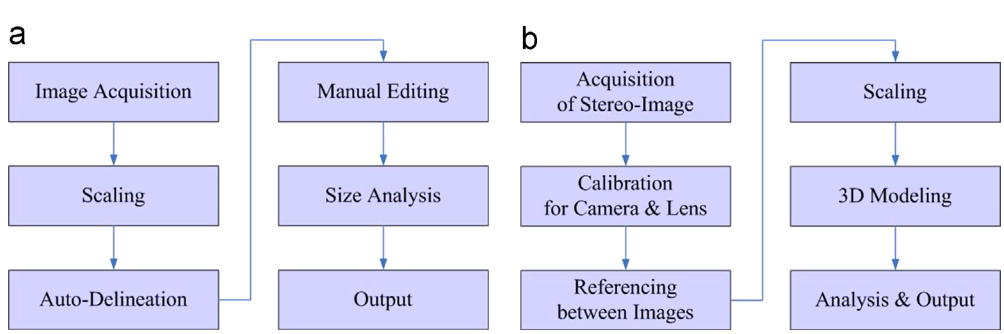

Fig. 1. Flowcharts of each software package approaches. (a) In Split Desktop, (b) in PhotoModeler scanner.