Novel Approach for Particle Size Distribution Analysis. Applied Case to Rockfills and Waste Dumps Using Unmanned Aerial Vehicle (UAV)

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Abstract. This paper describes the workflow and results for Particle Size Distribution (PSD) analysis using UAV photogrammetry for waste rockfill materials. A methodology for digital detection and statistical measurement of PSD derived from UAV-SfM photogrammetry is presented. The comparative results between field and digital measurements indicate that the average deviation, and standard deviation between the manually and digitally particle size vary between 12.3 mm and 49.9 mm for the field measurements and 16.9 mm and 52.5 mm for UAV in the different materials. PSD estimated using conventional and image processing shows a 4 mm an average difference between the measurements showing the potential use of the UAV technology and image processing to estimate PSD, leading to implement as standard practice aerial photogrammetry as an alternative to conventional sieve analysis for PSD estimation.

Keywords: Particle Size Distribution (PSD) · Unmanned Aerial Vehicle (UAV) · Photogrammetry

1 Introduction

Mining process requires the proper disposal of different types of waste material from which requires a deep understanding of the ground behavior through a rigorous geotechnical characterization to manage the risk. Accordingly, the particle size distribution (PSD) is fundamental for geotechnical design and construction, since PSD can affect the performance of granular materials, including their strength and load-bearing capacity [1].

PSD in waste dump plays a crucial role in multiple levels. For instance, the compaction of the rockfill can be affected by its PSD. For construction quality control, it is usually required that the rockfill PSD meets the design criteria [2]. Due to widely use of rock fills and waste dump for dam construction has driven new interest to investigate the physical and mechanical properties of rockfill material. In most cases, triaxial testing on the prototype rockfill using conventional laboratory equipment is unattainable as the sizes of aggregates used in the field are usually too large [3].

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This in turn emphasizes the need to develop appropriate methods to determine the PSD at real scale [4]. Traditionally, the particle size distribution for engineering materials is determined through physical sieve analysis using a series of screens with squared mesh [5]. For rockfill material there are no other accurate methodologies to establish PSD except visual rock gradation analyses relying heavily on the visual examination and engineer's experience for quality control during construction [6]. This method usually involves sieving of the finer fraction (i.e., up to 60mm) and physical measurements of coarser rocks using measuring tapes or other visual aids and it is expensive and time-consuming and not feasible for routine quality control purpose [7].

Commonly a full-scale gradation test on a rockfill and waste dump sample would require widely field work from engineers and field technician [8]. Machinery and safe handling procedures are also required for particle sizes more than 200 mm (i.e., heavier particles) [9]. Thereby, there is a strong motivation to establish a safer, faster, and simpler approach to assess the size distribution of rockfill material on a routine considering the actual development in computer and technologies [10].

With recent development in computation technology, image processing can be employed to determine the PSD of rockfill and waste dump materials [11]. Similar to conventional visual assessment, the image analysis technique allows researchers and engineers to inspect and measure visible particles within a digital photograph using computer algorithms [12]. This presents an optimization in rockfill and waste dumps for geotechnical characterization optimizing the time consumed to collect data and dedicate time to engineering analysis [13]. The availability of the UAV (Unmanned Aerial Vehicle) technology and the advances in computer image processing has opened the door to a new era with several possibilities to determine PSD using aerial photogrammetry, which has been used in topographical surveys and geological mapping for five years [14]. It is also an alternative to conventional sieve analysis for PSD estimation. Based on the forementioned background, this paper explores the use of UAV photogrammetry to determine the PSD, focusing on the workflow, results, and validation.

2 Case Studies

A total of five waste dumps were analyzed to validate the proposed methodology. The five waste dumps (Fig. 1) analyzed are described as follows:

- WD-1: Carbonaceous-Sediment mudstone with high Potential Acid Generator (PAG). The medium materials of WD-1 are minor boulders (PSD less than 1000 mm)
- WD-2: Limestone with low to medium physical alteration due to the tropical conditions. The PSD includes medium size boulders (Less than 200 mm), gravel and sand
- WD-3: Carbonaceous-Sediment mudstone with high Potential Acid Generator (PAG). The Medium materials of WD-3 are minor boulders (PSD less than 500 mm)
- WD-4: Volcanoclastic material and PAG material. Coarse and rocky material with low content of fines
- WD-5: Volcanoclastic material and PAG material. The material is coarse and rocky with low content of fines

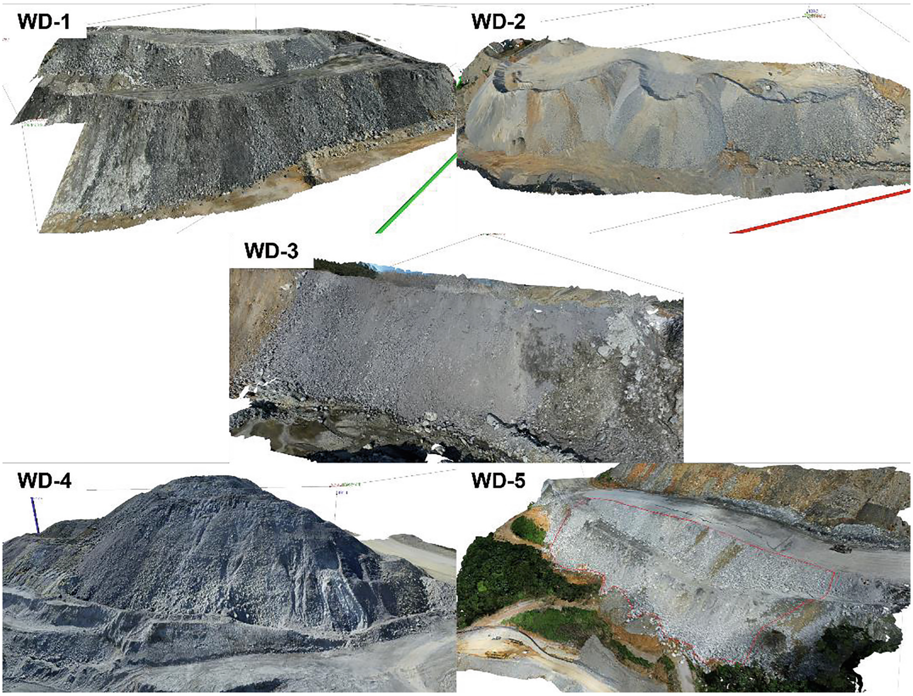

Fig. 1. Orthorectified view of the 5 waste dumps (3D view generated from UAV photogrammetry).

3 Method

3.1 Sieve Analysis for PSD

Mechanical sieving is the most commonly used method to determine the particle size distribution of rock and soils [15]. Basically, the sieving operation attempts to divide a sample of aggregate into fractions, each consisting of particles within specific size limits [16]. Before the sieving starts, the sieves are stacked up with the smallest one at the bottom and the largest one at the top (Fig. 2).

3.2 PSD Using UAV

For processing a UAV high-resolution image was acquired. The images were analyzed using Fragmenter from 3GSM [17]. A classic field survey with a metric tape was performed to validate particle size from the image processing (Fig. 3). Fifty (50) rocks boulders were sampled (10 samples per waste dump) and measured for the validation process.

Workflow showed in the Fig. 4 consists of four steps: (Step 1) 3D model reconstruction using UAV digital photogrammetry, (Step 2) selection and discretization of the area to be analyzed, (Step 3) automatic characterization of PSD, and (Step 4) PSD plots and grain size analysis.

Fig. 2. Conventional sieve analysis for PSD

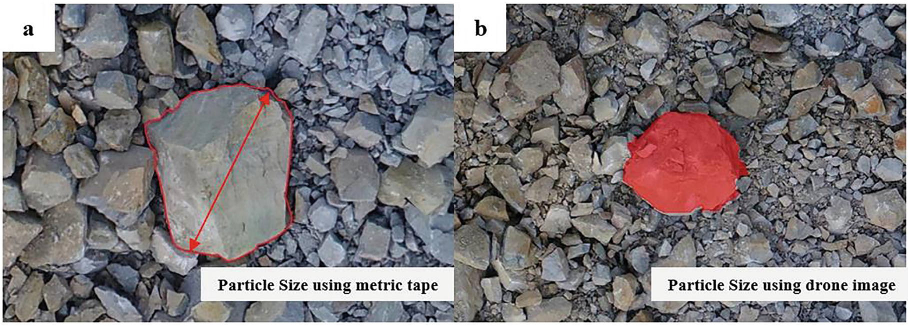

Fig. 3. Particle size using manual and image processing. (a) Manual measures using metric-tape for particle size. (b) Particle size using image processing.

3.3 3D Point Cloud and Model Reconstruction

The red/green/blue (RGB) images taken with a UAV are used as input for the reconstruction of the 3D model as a point cloud employing Structure from Motion (SfM), a photogrammetry technique that uses computer algorithms to extract key points in overlapping images taken from multiple view angles to create 3D models [18].

From a collection of 2D images obtained from multiple positions and/or angles, SfM processing reconstructs a 3D structure of a stationary scene via motion estimation of the camera corresponding to each image [19]. To promote the application, an easily accessible software, Fragmenter (available at https://3gsm.at/produkte/bmx-fragmenter/) was employed in this study according to the workflow showed in the **Fig. 4**.

For the field image acquisition, a quadcopter platform, DJI Mavic Pro quadrotor drone, equipped with an 1/2.3″ (CMOS), Effective pixels:12.35 M (Total pixels:12.71M) was employed for photogrammetric survey [20]. Field works were performed in three steps: (1) flight mission designed, (2) ground control points (GCPs) placement and acquisition, and (3) flight operation and aerial images collection.

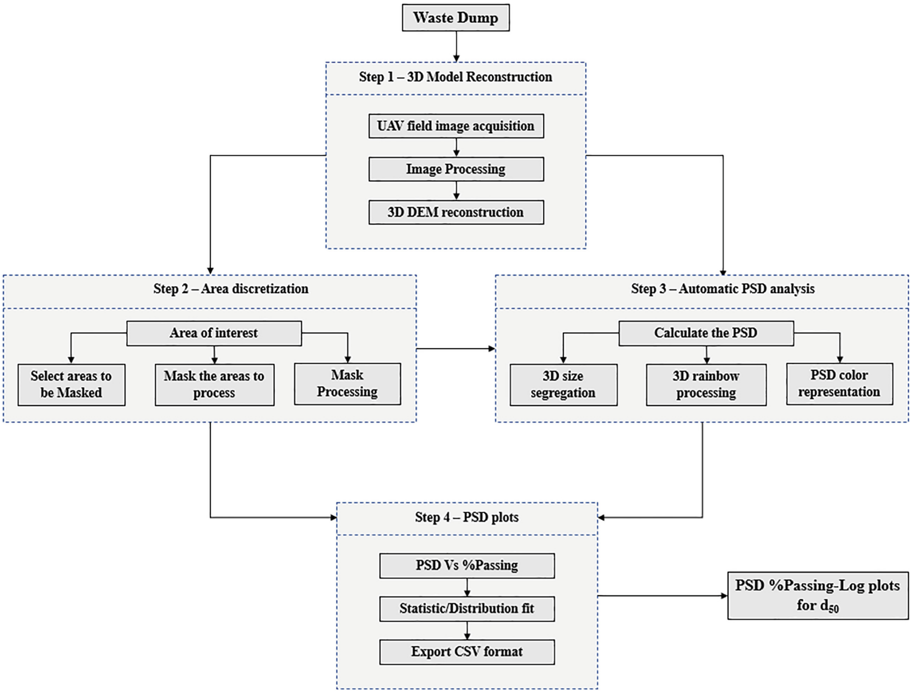

Fig. 4. Workflow for PSD using UAV photogrammetry

4 Discussion

4.1 Validating Particle Size Through Digital Analysis and Metric Tape Field Measures

In order to validate the PSD from the UAV, 50 individual samples, 10 per waste dumps (refer to Table 1). Were selected to compare the digital analysis and field measurements using metric tape to measure the individual diameter in the selected samples. PSD variation between UAV estimation and field metric tape:

- WD-1, the average deviation and standard deviation between the manually and digitally particle size are 12.3 mm and 16.9 mm with a difference between mean values of 14 mm.
- WD-2, the average deviation and standard deviation are 43.3 mm and 42.4 mm with a difference between mean values of 1 mm.
- WD-3, they are 21.7 mm and 14.2 mm with a difference between mean values of 6 mm.
- WD-4, they are 49.9 mm and 52.5 mm with a difference between mean values of 3 mm.
- WD-5, they are 41.0 mm and 39.1 mm with a difference between mean values of 6 mm.

Table 1. Comparison of the results between digital analysis and field tape measurements for particle size.

Site	Method	Number of data sets	Mean value (mm)	Std	Error (%)
WD-1	Field	10	232	16.9	5.3
	UAV		218	12.3	3.9
WD-2	Field	10	241	43.3	13.7
	UAV		240	42.4	13.4
WD-3	Field	10	205	21.7	6.9
	UAV		199	14.2	4.5
WD-4	Field	10	217	49.9	15.8
	UAV		220	52.5	16.6
WD-5	Field	10	248	41.0	13.0
	UAV		242	39.1	12.4

A deviation ratio (DR, Eq. 1) is defined to validate the error between digital analysis results and field tape manual measurements. The average DR values for the five cases studies are (**Fig. 5**):

- WD-1 = 6.9%,
- WD-2 = 5.3%,
- WD-3 = 5.7%,
- WD-4 = 4.4%
- WD-5 = 4.7%,

$$DR = \frac{\Delta|PS|}{PS_{Tape}} \tag{1}$$

4.2 PSD Using UAV

The SfM technique, applied to the selected waste dumps, returned scattered point clouds between 201,225 points and 502,594 points, respectively [21]. The optimization of the cloud, by reporting the GCP field arrangement, allowed the minimization of the reprojection error and the generation of several dense point clouds made up of about 190 mln points and 450 mln points for all the sites respectively. Mapping involved the acquisition of multiples photos aiming to collect and determine the geometric details of the rock fill and waste dump particles [22].

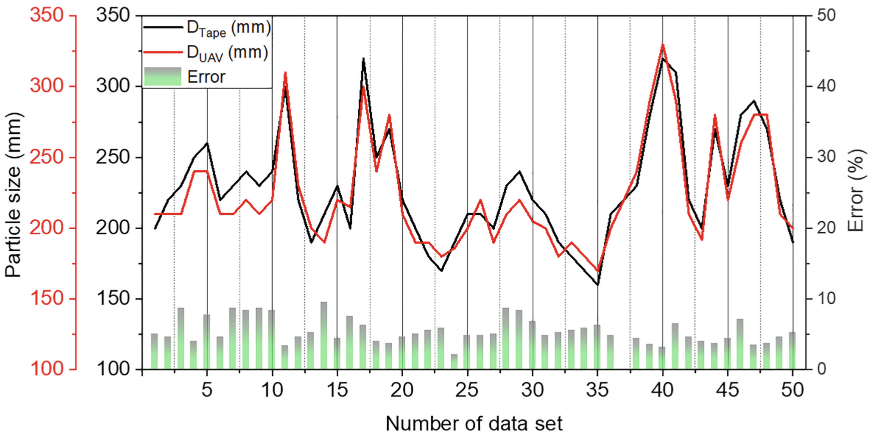

Fig. 5. Variation between digital analysis and field tape measurements

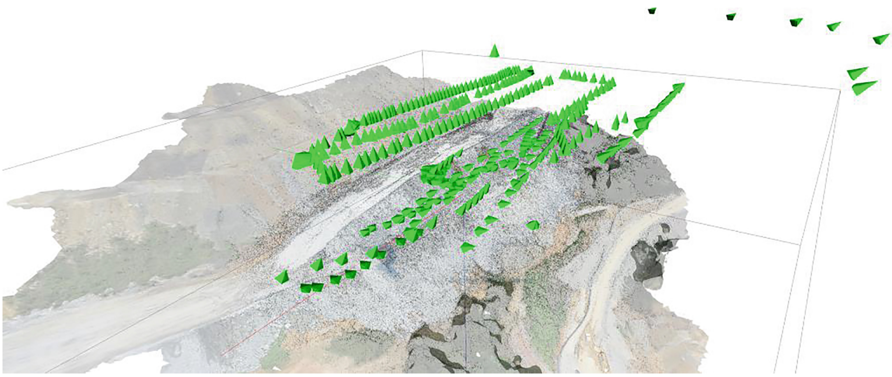

Fig. 6. Location and orientation of photographs relative to point cloud.

A total of 3855 images were taken and analyzed including rockfill materials with particle sizes ranging from sand and gravel to boulder sizes of up to 1000 mm. The images have been taken from an average distance of 30 m-120 m from the waste dumps and rockfill slope surface, yielding an estimated Ground Sample Distance of about 1 cm. ShapeMetrix UAV software has been used to georeferenced and manage the point clouds and to quantify the PSD features [23]. Figure 6 shows the photographs orientation and Fig. 7 the waste dump 3D model.

The PSD data assessed from the 5 waste dumps is showed in Fig. 8. The subdivision of each subarea allows to have multiples curves for the PSD per waste dump. Since multiple sources of data can increase the confidence in the model, a bigger dataset for PSD and high accuracy in the results will be achieved [24].

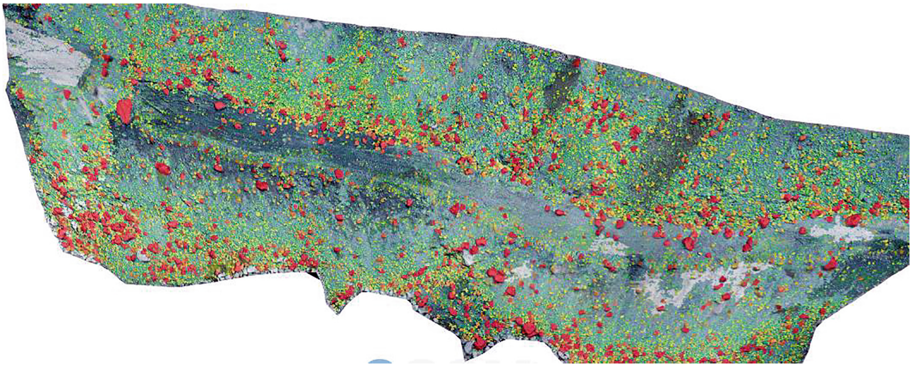

Fig. 7. Waste dump 3D model comprising > 7 million points and > 2.6 million mesh elements

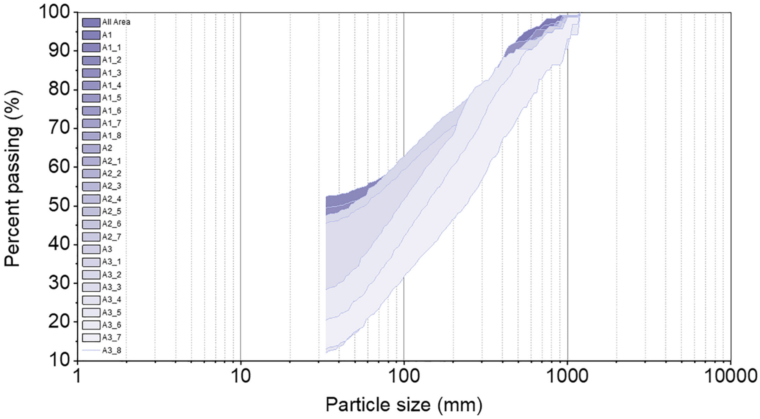

Fig. 8. PSD curve.

5 Conclusions

The comparative results between field and digital measurements indicate that the average deviations, and standard deviations between the manually and digitally particle size vary between 12.3 mm and 49.9 mm for field measurements and 16.9 mm and 52.5 mm for UAV with an average difference between the mean values of 4 mm. These well-matched results indicate that the UAV-SfM photogrammetry based digital analysis can effectively identify and characterize the PSD for rock fills and waste dumps. Compared with the field measurements that are strongly restricted by measurement environments, the developed digital method is flexible, and the achieved results are reproducible.

The digital analysis also shows some shortcomings, for example, it inevitably to not captures very fines material. To date, remote sensing techniques and the related digital analysis should be regarded as a complement to manual survey but not a replacement. This study attempts to introduce the low-cost and lightweight UAV photogrammetry technique into the waste dump characterization, the development of which in the future may become an important part in the next-generation field survey methods.

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