UAV Photogrammetry for Volume Calculations. A Case Study of an Open Sand Quarry

Giuessppina Vacca(✉)

Department of Civil and Environmental Engineering and Architecture, University of Cagliari, 09123 Cagliari, Italy
vaccag@unica.it

Abstract. Traditional geomatic surveying techniques for calculating volumes of bulk or extracted material have evolved in recent years. From the traditional GNSS or total station survey to the current UAV photogrammetric system with the Structure from Motion (SfM) approach. The calculation of the volumes of bulk or landfill materials is of considerable importance both from an economic point of view and from an environmental point of view. The emergence of unmanned aerial vehicles - UAVs made it possible to automate the entire volume detection process, as well as reduce the time required for detection itself. This paper presents the calculation of the volume for the heaps of material (sand) on an open sand quarry with the use of UAV and multimages Close Range Photogrammetry. The survey was carried out on the same sand quarry in two successive time with the DJI Phantom 4 UAV. The images processed with the Metashape software, and the volume calculation performed with the Cloud Compare software.

Keywords: Volume · Comparison · UAV · Metashape · SfM · Cloud Compare

1 Introduction

Thanks to the technological development of recent years relating to UAV technology both from the hardware point of view and from the software point of view in relation to image processing, the use of UAVs in the various aspects of sustainable engineering has increased significantly. The possibility of detecting the territory in safety, with fast times, at low cost and with low environmental impact has facilitated its use in various areas it has had a significant impact in mine engineering operations especially for the survey and volume calculation of a quarry [1].

The good management of a quarry requires precise data obtained in a short time. For quarries, its continuous survey is important to monitor its evolution. In general, these monitoring are intensified during the periods of removal of the material, and this leads to the need to use fast and accurate survey methods [2]. In the past, the monitoring and calculation of volumes were performed with traditional topographic methods using Total Stations or the Global Navigation Satellite System (GNSS) in Real Time Kinematic mode. These systems are still used but have problems relating to access and safety of

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the quarry, costs and survey times which can be several days depending on the size of the quarry [3, 4].

Another method used is the Terrestrial Laser Scanner (TLS) which, however, presents greater difficulties both in the survey phase and in its processing, as well as high costs. [5–7]. UAV Photogrammetry is an alternative to TLS with the advantage of being cheaper, faster and simpler. By use of the Structure from Motion (SfM) approach, it is possible to generate dense cloud points of high accuracy that can be used for the calculation of volumes. There are many experiences that have shown its accuracy, reliability, low costs and fast times [8–10] that have made it one of the most used techniques in monitoring quarries.

The paper presents the first results obtained from research in this field. In particular, the study of the workflow for calculating the volumes of a sand quarry is presented, evaluating the best parameters to produce point clouds to be used for the calculation of the collected material. In this first phase of research, Metashape software by Agisoft was used to produce point clouds and Cloud Compare software for the calculation of volumes. The research is continuing evaluating the potential of this methodology in terms of accuracy, time and difficulty compared to the methods used in this quarry for its monitoring.

2 Materials and Method

The paper concerned the study of the potential of calculating volumes using multimages photogrammetry from UAVs with the aim of testing an economical, fast and accurate workflow that can be easily used in the frequent monitoring of quarries. The workflow studied involved two of the most popular software for processing images from UAV surveys and for processing dense point clouds: Metashape Professional 1.7.2 and the open source software Cloud Compare.

The volume was calculated between two UAV flights performed in May 2021 and February 2022 over a sand quarry. The procedure was evaluated exclusively based on processing times and on the parameters that can be used for the calculation. As for the accuracy of the UAV photogrammetry method, already widely positively evaluated by the scientific literature reported in the introduction, it will be the subject of a forthcoming publication.

In the following paragraphs the case study, the methodology followed, and the instrumentation used will be described.

2.1 Case Study

The case study is a quarry located in the municipality of Serdiana (Italy) in the locality of S'Isca Manna. It is a sand quarry of about 5.4 ha. Figure 1 shows the quarry.



Fig. 1. S'Isca manna quarry (image from google earth)

The quarry has an average altitude of about 270 m above mean sea level. Around the quarry there is a thick vegetation with trees (Table 1).

Table 1. Geographic coordinate of the quarry

	Latitude	Longitudine
East	39°25′21.39″ N	9°10′57.37″ E
West	39°25′22.55″ N	9°10′45.24″ E
North	39°25′26.76″ N	9°10′54.30″ E
South	39°25′15.18″ N	9°10′50.81″ E

2.2 UAV Survey

The DJI Phantom 4 drone was used for May 2021 and February 2022 flights. Table 2 shows the characteristics of the UAV used (Table 3).

Table 2. DJI Phantom 4 specifications

Size	Diagonal 35 cm
Wight	1,375 kg
Max flight time	30 min
Max speed	13–89 m/s
Rotors	4
Camera	Yuneec E90
Pixel	5472 × 3080
Focal lenght	8.3 mm
Pixel size	2.41 micron
Image format	Jpeg, DNG (Raw)

Table 3. UAV survey

	May 2021	February 2022
Area covered by the images	16 ha	13 ha
Flight height	50 m	56 m
GSD	1.34 cm	1.5 cm
Longitudinal overlay	80%	80%
Transversal overlay	70%	70%
Number of strips	40	35
Number of images	1026	670

Figure 2 shows Phantom 4 and the wooden target used, during the UAV flights, to materialize the Ground Control Points (GCP).

The images were georeferenced using the Ground Control Points (GCPs) signaled with wooden circular targets with a diameter of 24 cm (Fig. 2b). The shape and size of the targets have been planning to be visible on images acquired from a height of about 50 m. The points were surveyed using a GNSS receiver in RTK mode with the ITALPOS Permanent Stations Network [11] determining their coordinates in the ETRF2000 datum with geodetic height.

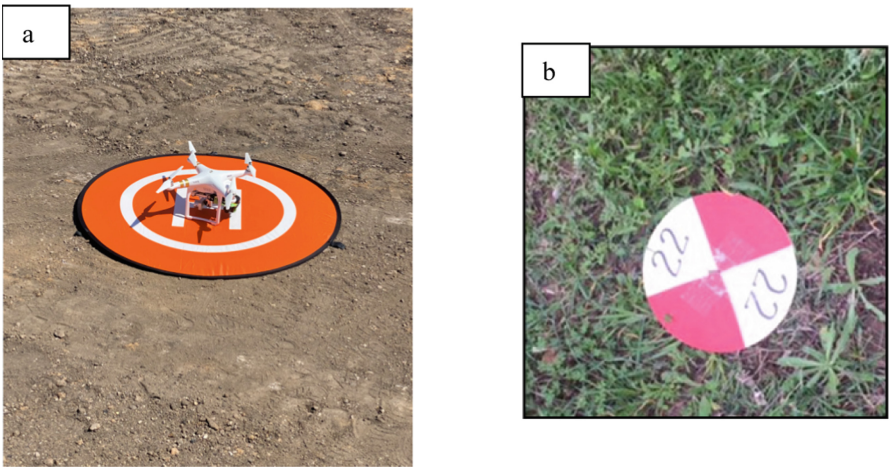

Fig. 2. Phantom 4 (a) and GCP target (b)

For the May 2021 UAV flight, 10 points were survey, of which 7 were used as Ground Control Points (GCPs) and 3 as Check Points (CP). For UAV flight February 2022, 19 points were survey, of which 10 were used as GCPs and 9 CPs.

The images from both surveys were processed using Metashaphe by Agisoft [12] software that implements the Structure from Motion (SfM) algorithm. The SfM is a low-cost photogrammetric method for high-resolution topographic reconstructions. The SfM operates under the same basic tenets of the stereoscopic photogrammetry. However, they fundamentally differ because in SfM the geometry of the scene, camera positions and orientation are solved automatically without points known. In the other method, instead, points are solved simultaneously using a highly redundant, iterative bundle adjustment procedure, based on a database of features automatically extracted from a set of multiple images with a high degree of overlap [13].

The Metashape workflows consist in the following main steps: image import, image alignment, generation of the sparse point cloud, optimization of image alignment, georeferenced, generation of the dense point cloud, generation DEM and generation orthophoto [14, 15].

The processing of the dense cloud points of the two flights was performed with different quality to evaluate the influence of this on the volume calculation and consequently also to evaluate the processing times. We then proceeded to photogrammetric process with the densities provided by Metashape: High, Medium, Low, Lowest. The processing times for the generation of clouds were various, so it is of interest to evaluate whether it is necessary to produce a dense cloud (High) or if we can reduce point cloud density. The images have processed on an HP Z420 workstation with 64 GB RAM, Intel Xeon E5–16200 3.60 GHz CPU, and NVIDIA Quadro K2000 video card.

After having generated the dense point clouds for 2021 and 2022 UAV flights, these were georeferenced in the Datum ETRF2000, we proceeded to calculate the volumes with the open source software Cloud Compare. It is a software created for the processing of point clouds and has many tools for manually editing and rendering 3D points clouds

and triangular meshes. It also offers various advanced processing algorithms for the registration, distance computation, segmentation etc. Among the various algorithms implemented, the calculation of volumes 2.5 between two point clouds of different epochs or with respect to a reference plane is envisaged. This tool was used to determine the volume between the point cloud of May 2021 compared to that of February 2022.

3 Results

Below are the results obtained from the processing of the images of the flights in May 2021 and February 2022 and the calculation of the volumes.

3.1 UAV Survey May 2021

May 2021 UAV flight images were processed with Metashape software with High, Medium, Low and Lowest dense cloud quality. Figures 3 and 4 show the scattered and dense clouds produced for the High quality. The georeferencing in the ETRF2000 Datum was performed with the use of 7 GCPs. Also 3 CPs were used to check the validity of the georeferencing. Table 4 shows the RMSE of the GCPs and CPs. Figure 5 shows the arrangement of the GCPs and CPs.

Table 5 shows the number of points for each dense point cloud produced and the time taken to process the entire photogrammetric process.

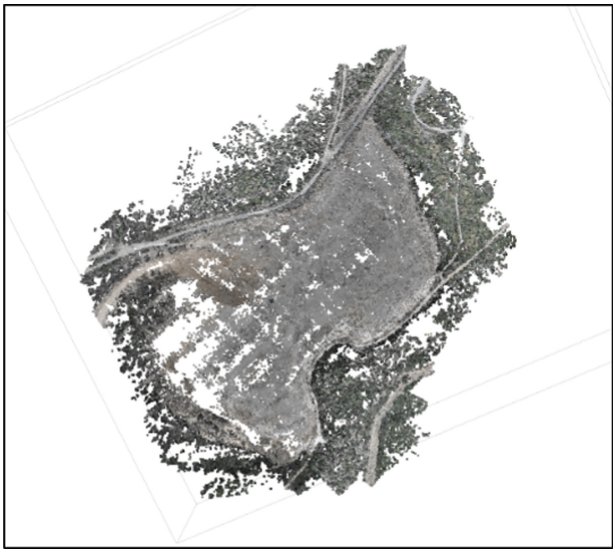

Fig. 3. Scattered point cloud May 2021



Fig. 4. Dense point cloud May 2021

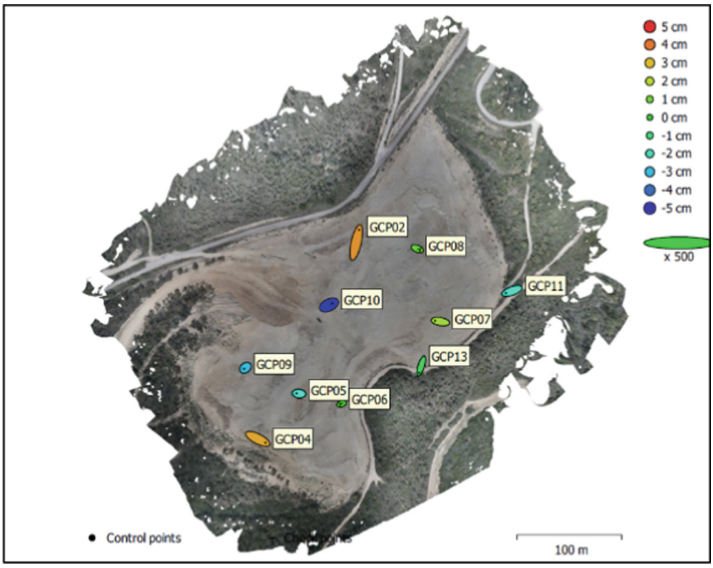

Fig. 5. GCPs positioning May 2021

Table 4. GCPs and CPs RMSE

	East (m)	North (m)	Height (m)
GCPs	0.017	0.021	0.025
CPs	0.011	0.005	0.028

Table 5. Dense point cloud and time - UAV survey May 2021

	High	Medium	Low	Lowest
N. points	274.531.436	70.769.526	17.698.572	4.241.950
Processing time (h)	32	11	5	4

Figure 6 shows orthophoto with Ground Sample Distance (GSD) of 1, 5 cm.



Fig. 6. Orthophoto May 2021

3.2 UAV Survey February 2022

February 2022 UAV flight images were processed with Metashape software with High, Medium, Low and Lowest dense cloud quality. Figures 7 and 8 show the scattered and dense clouds produced for the High quality. The georeferencing in the ETRF2000 Datum was performed with the use of 10 GCPs. 9 CPs were also used to check the validity of the georeferencing. Table 6 shows the RMSEs of the GCPs and CPs. Figure 9 shows the arrangement of the GCPs and CPs. Table 7 shows the number of points for each dense point cloud produced and the time taken to process the entire photogrammetric process (Fig. 10).

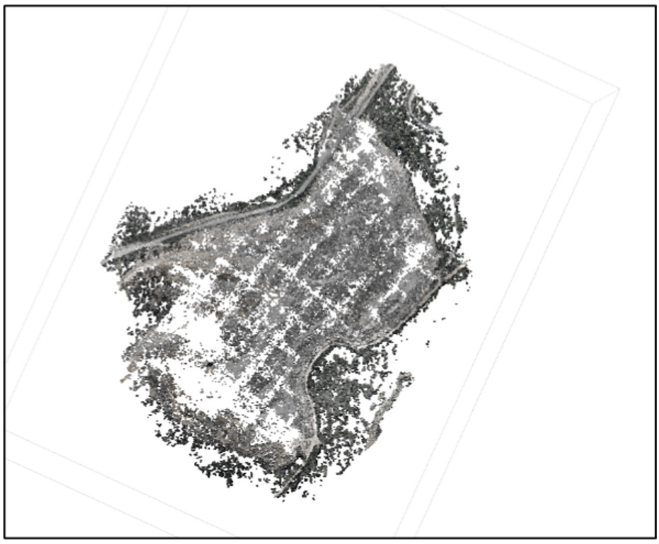

Fig. 7. Scattered point cloud February 2022

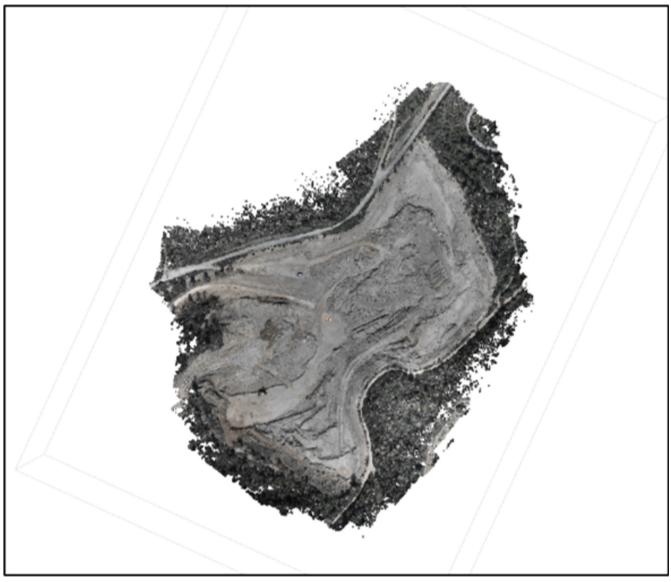

Fig. 8. Dense point cloud February 2022

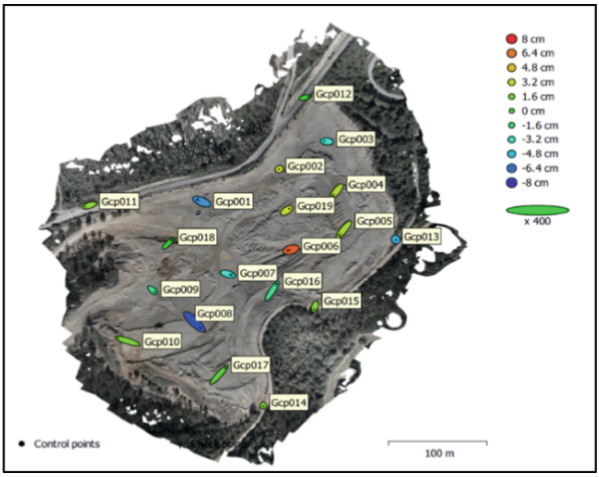

Fig. 9. GCPs positioning February 2022

Table 6. GCPs and CPs RMSE

	East (m)	North (m)	Height (m)
GCPs	0.019	0.009	0.029
CP	0.025	0.028	0.042

Table 7. Dense point cloud and time - UAV survey February 2022

	High	Medium	Low	Lowest
N. points	150.052.986	39.326.072	10.035.972	2.441.419
Processing time (h)	22	6	3	2

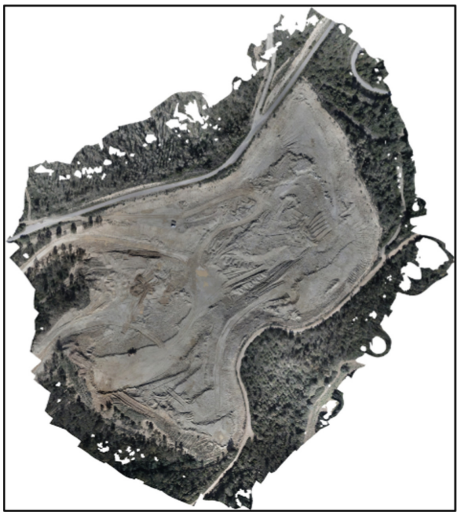

Fig. 10. Orthophoto February 2022 (GSD 1, 5 cm)

3.3 Volume Calculation

To calculate the volume of material removed from May 2021 to February 2022, the Cloud Compare software was used through the Compute 2.5D tool. This tool can be used to compute the volume between a 2.5D cloud and an arbitrary plane (constant height) or between two 2.5D clouds. Preliminarily to the calculation of the volume, the maps of the distances between the point clouds coming from the two UAV flights were calculated and processed at the various densities. This was done comparing the measurements of distances taken on the point clouds obtained from the two UAV survey. To perform this comparison, equal portions of point clouds were taken.

Figures 11 and 12 show the results of this comparison for the High and Lowest quality.

The volume calculation was performed on the dense point clouds 2021 and 2022, also in this case cut, respectively for High, Medium, Low and Lowest quality. The calculation was done by varying the sampling step required in the 2.5D calculation. The volumes were calculated with 1 m and 0.5 m pitch and not considering the empty cells (Fig. 13). Table 8 shows the results obtained.

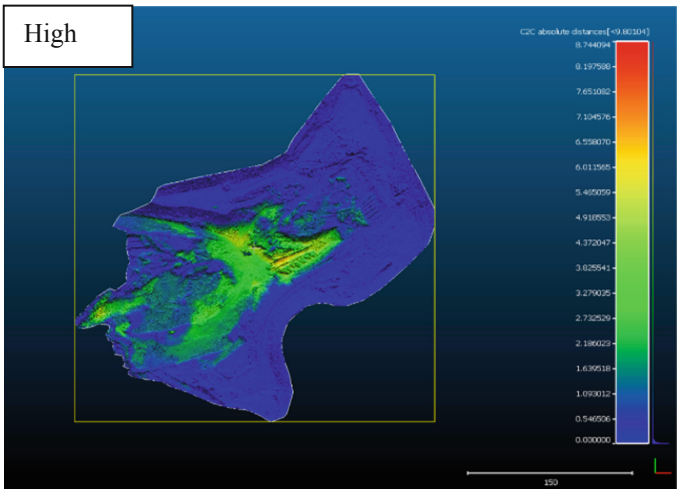

Fig. 11. Discrepancy (m) map between UAV surveys 2021 and 2022 – High

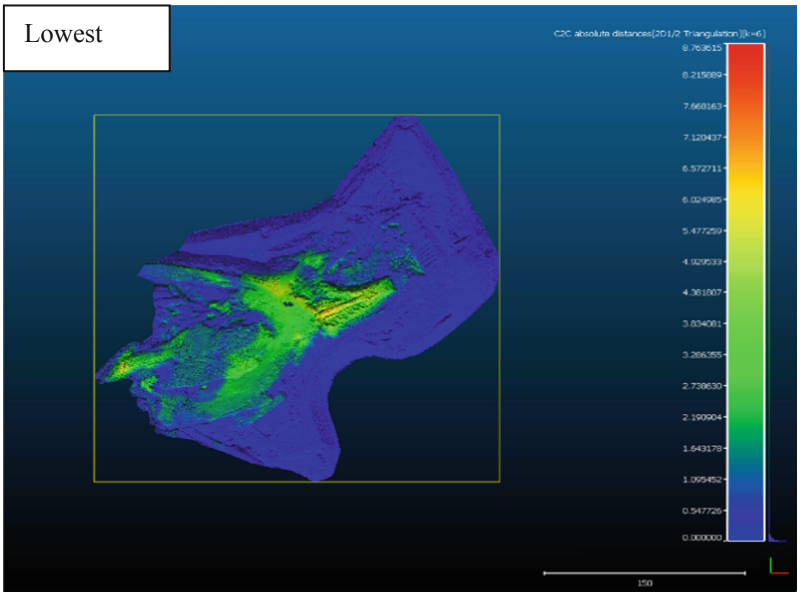

Fig. 12. Discrepancy (m) map between UAV surveys 2021 and 2022 – Lowest

Table 8. Volume calculation

		Sampling step	
		1 m	0, 5 m
Quality	High	45.342 m^3	45.185 m^3
	Medium	45.361 m^3	45.248 m^3
	Low	45.113 m^3	44.956 m^3
	Lowest	45.417 m^3	45.226 m^3

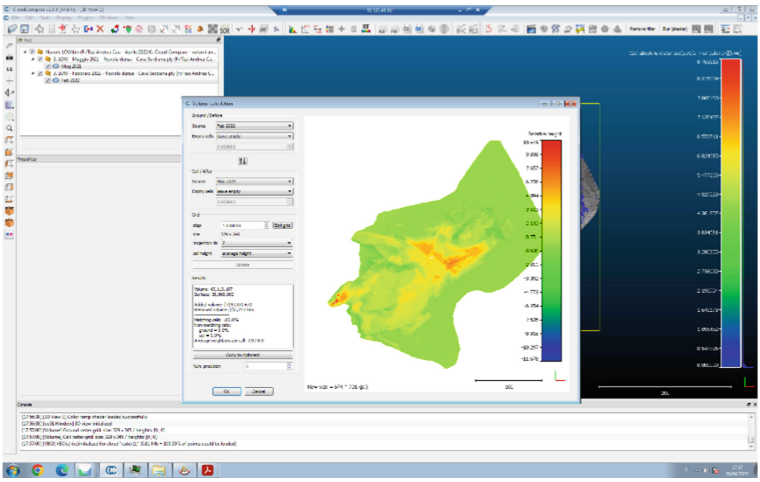

Fig. 13. Tool compute 2.5D - cloud compare

4 Discussion and Conclusions

From the first research carried out we can say that the procedure tested for calculating the volumes of the quarries certainly leads to confirm the results already obtained from other research [16]. For the calculation of volumes, images from UAVs obtained with a Low quality can be used as the variation in quality never produces volume variations greater than 1% compared to the value obtained with High quality. Even the difference in sampling step does not lead to substantial differences with respect to the sampling step of 0.5 m. Therefore, since as the quality of the dense cloud increases, there is a significant increase in processing times, it is possible to use lower point cloud qualities. The same can be said for the sampling step between 1 m and 0.5 m.

The distance map is also a good method for monitoring the most exploited areas of the quarry.

The research continues by testing the accuracy by comparing the volumes calculated with the UAV Photogrammetry with the SfM approach and the volumes calculated using point clouds from Terrestrial Laser Scanner.

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