Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering. Vol. VIII, 2019
Print ISSN 2285-6064, CD-ROM ISSN 2285-6072, Online ISSN 2393-5138, ISSN-L 2285-6064

DETERMINING STOCKPILE VOLUMES USING PHOTOGRAMMETRIC METHODS

Tudor SALAGEAN[1], Elemer-Emanuel SUBA[1, 2], Ioana Delia POP[1], Florica MATEI[1], Jutka DEAK[1]

[1]University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, 3-5 Calea Manastur Street, Cluj-Napoca, Romania
[2]Technical University of Civil Engineering Bucharest, 122-124 Lacul Tei Blvd, Bucharest, Romania

Corresponding author email: popioana@usamvcluj.ro

Abstract

Stockpile volume measurement is very important, especially in highway construction sites. Monitoring inventories, as well as keeping records of stockpiles, is one of the key elements in the success and optimizing the construction site works. Inventories in the case of construction sites are constantly changing; the raw material stored is on the one hand supplied by the suppliers and on the other hand transported and used on the site. Within this paper we aim to compare different methods of measuring and determining volumes. We also develop a workflow for UAV photogrammetric measurements and compare the volumes obtained with different specialized software. Using different software even on the same UAV data set, we obtained relatively similar results, the differences being due mainly to the different 3D modelling of the surfaces. To determine as precisely as possible highway construction sites, stockpile volumes the UAV photogrammetric method is the most precise in terms of the accuracy of the results obtained. This method also saves a lot of time on the site and is also risk free.

Key words: *drone, photogrammetric, point cloud, stockpile volume, UAV technology.*

INTRODUCTION

Determining stock volumes is an activity of particular importance.
Monitoring inventories, as well as keeping records of raw materials as accurate as possible, is one of the key elements in the success of the works.
Inventories in the case of construction sites are constantly changing; the raw material stored is on the one hand supplied by the suppliers and on the other hand transported and used on the site. We can compute the stockpile volumes using various methods like: terrestrial measurements using a total station, GNSS techniques, photogrammetry and the newest technology, laser scanning (Raevaa et al., 2016).
In order to manage efficiently a stockpile, it is required a fast and accurate data gathering. Gaining up-to-date information consists of continuous surveying the constantly changing shape of the stockpile and its elements and computes the volume. Monitoring could take place weekly, monthly or every 3 months (Mazhrakov, 2007).
The UAV techniques combine aerial and terrestrial photogrammetry but also introduce low-cost alternatives to the classic methods (Carvajal et al., 2011).
Comparing to classical volume measurement methods, close range photogrammetry is a more efficient method. The time required for collecting spatial information id much reduced. The accuracy of the volume calculation is proportional to the presentation of the land surface. The presentation of the surface on the other hand is dependent on the number of coordinated points, their distribution and its interpolation (Raevaa et al., 2016).

MATERIALS AND METHODS

Nowadays UAV platforms are becoming more and more accessible, and photogrammetry is used frequently.
Classical measurements, which are very time consuming, can be easily replaced by laser

scanning, UAV measurements and other automated workflows.

In this paper we used various techniques and instruments. First for determining the position of the ground control points we used two dual band (L1 L2) GNSS receivers, in base rover-radio setup. The base station is presented in Figure 1. The base point was marked with a FENO Landmark, as presented in Figure 2. We chose to mark the exact position of the base station, as we determined it with static GNSS measurements, and we plan to use it for numerous surveys performed during the monitoring of the stockpile. We chose the location of the base station outside the perimeter for safety reasons so that the workers won`t disturb it.

Figure 1. Dual band GNSS receiver - base station

Figure 2. Base point - FENO Landmark

For the photogrammetric work we used a Phantom 4 Pro Drone (Figure 3), having an on board, 20-megapixel camera with 1” CMOS sensor.

Figure 3. DJI Phantom 4 Pro Drone

For processing the data, we used various software products like: Dronedeploy, Agisoft Photoscan, Global Mapper and AutoCad.

Usually specialized software determines the pile volume(s) by calculating the volume of a pile as defined by an area feature by creating sample elevations along the perimeter of the selected area feature to form the 'base' surface. The elevation values for each sample will be where the elevation value from where the sample point intersects with the loaded elevation model (Global Mapper Help, 2017).

The sample spacing is determined by the width of the area feature and the height of the pile. It will be 1/200 th of the width of the selected area feature, or 1/200 th of the height of the pile - whichever is the smallest interval. For example, a pile that is 50 m width by 40 m tall will have its boundary resample at 0.2 m spacing (40 m/200 m = 0.2 m) (Global Mapper Help, 2017).

The volumes are then calculated by creating a terrain surface from the pile area, calculating the area surface from the generated terrain surface, and then subtracting from the actual terrain (Global Mapper Help, 2017).

To use the Pile Volume measurement tool, we will need an area feature that encompasses the hill or pile we would like to measure the volume of, or you will need to digitize a new area feature around the pile. The area feature does not need to have elevations defined for vertices, as the elevation values to calculate the Pile Volume will be derived from the generated samples (Global Mapper Help, 2017).

For a more accurate measurement, we need to make sure the area feature fully encloses the pile or hill, without having a lot of space around the perimeter (Global Mapper Help, 2017).

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RESULTS AND DISCUSSIONS

Within this paper we determined the stockpile volume from A3 highway construction site from Abram, Romania. The new A3 highway it`s part of the national highway routes and this specific section is 60 km long which connects Bors (border to Hungary) and Suplacu de Barcau. This particular section has two major material stockpiles, one in Abram at km 21.7, and another in Salard at km 50.5, so that the distance that the vehicles most cross for delivering materials is minimized as much as possible. As a first step we picked the location and marked the ground control points inside the perimeter, so that the GCP`s are evenly distributed (Figure 4).

Figure 4. Ground control points location

The next step we made is planning the flight. We programmed the drone using Dronedeploy for a flight at 100 m above ground and a front overlap of 75% and side overlap of 65%.
Because the drone takes as reference the take-off point, we didn`t get the same results as programmed.
In Figure 5 it can be seen the location and the actual overlap of the cameras.

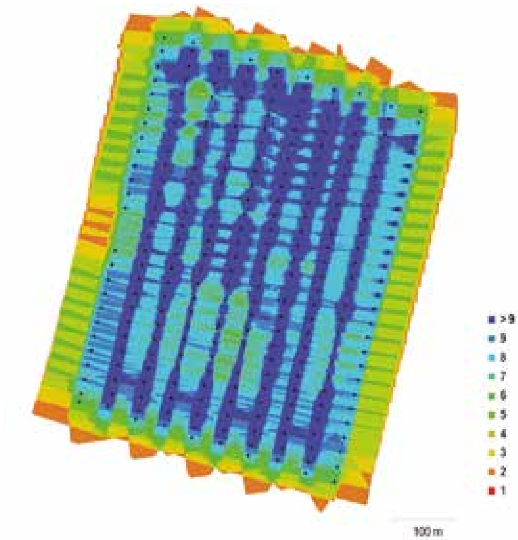

Figure 5. Camera locations and image overlap

Due to the GNSS receiver precision, and the Ground control points marking, we obtained a total planimetric error of 0.01701m. The total altimetry error was 0.0110m as it is presented in Table 1.

Table 1. Ground control points and errors (RMSE)

GCP	XYerror (m)	Zerror (m)	Projections	Error (pix)
2066	0.02231	0.0103	10	0.3860
2067	0.02582	-0.0304	6	0.3130
2068	0.01892	-0.0066	11	0.2090
2069	0.00538	0.0092	7	0.2220
2070	0.00944	-0.0023	10	0.2460
2071	0.01807	0.0014	10	0.2000
2072	0.01844	0.0010	8	0.2820
2073	0.01238	0.0063	7	0.1390
2074	0.01756	-0.0100	8	0.2080
1148	0.01939	-0.0042	8	0.2610
1153	0.00618	-0.0022	6	0.2390
Total	**0.01701**	**0.0110**		**0.2550**

Regarding the fact that we are intending to compute stockpile volumes, we are more interested in altimetry, so we consider the results satisfactory to compute the volumes. The block compensation of the aero-triangulation error was computed as root mean square error (RMSE) (Vorovencii, 2010) as it results from the equations 1 to 5.
Average square error:

$$\sigma_0 \quad \pm\sqrt{\frac{|vv|}{r}} \qquad (1)$$

Where r - compensation redundancy.

$$r = 3(n'_R + n'_L) - (7n_M + 3n_L) \qquad (2)$$

- n_M - no. stereomodel blocks;
- n_L - no. pass points;
- n'_R - total no. of control points appearances on n_M models;
- n'_L - total no. of control points appearances on n_L models.

The root mean square errors in control pass and sparse points are calculated as follows:

$$e_R \quad \pm\sqrt{\frac{[v_{X_R}^2 + v_{Y_R}^2 + v_{Z_R}^2]}{3n'_R}} \qquad (3)$$

$$e_L \quad \pm\sqrt{\frac{[v_{X_L}^2 + v_{Y_L}^2 + v_{Z_L}^2]}{3n'_L}} \qquad (4)$$

$$e_C \quad \pm\sqrt{\frac{[v_{X_C}^2 + v_{Y_C}^2 + v_{Z_C}^2]}{3n'_C}} \qquad (5)$$

After obtaining the digital elevation model in Agisoft, we could compute the volume, directly, just by making a perimeter for the stockpile and then determining the exact volume. We performed a case study on the site of the new A3 highway, on the two stockpiles, one at km 21.7 in Abram, and another at km 50.5 in Salard. The stockpiles were specifically numbered as shown below in Figure 6. According to the requests of the beneficiary constructor, all the results will be reported with these names, and numbering of the stockpile, so that we could better keep the inventory of the crushed stone and other materials stored there.

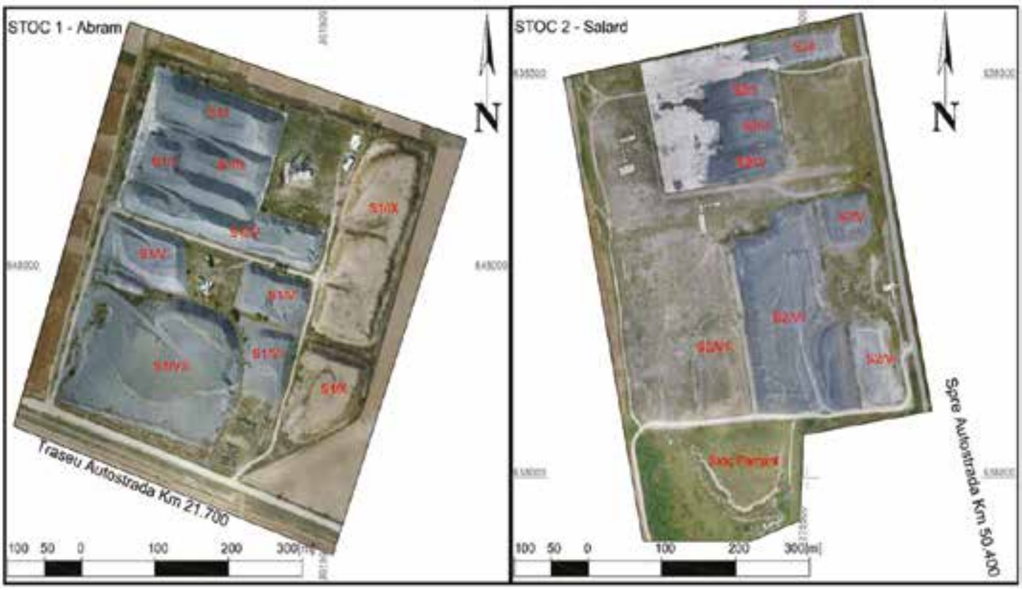

Figure 6. Stockpiles taken into the case study

We performed the volume computation using directly Agisoft Photoscan. The surface used for volume computation was the DEM, derived from the dense point cloud. In order to compute the volume, we had to draw a polyline, determining the contour of the stockpile. This polyline was drawn on the orthophotomap. In Figure 7 the volume computation for stockpile plot 1 is presented.

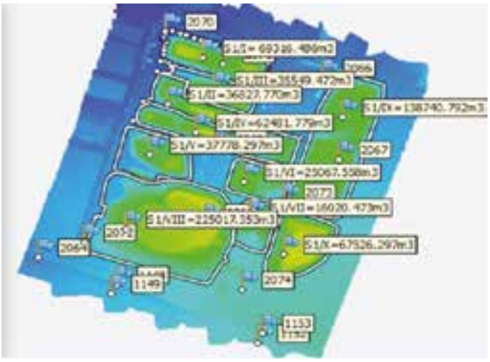

Figure 7. Stockpile volume computation using Agisoft Photoscan

For determining the right value for stockpile volume, we have to choose from a set of options in Agisoft Photoscan. The software computes the volume above the best fit plane, the volume above mean level, and the volume above a custom level. If the stockpile is inaccessible from the margins, or it is very close to other stockpiles, than we cannot use the option of computing a best fit plane. We will have to find a custom level and compute the volume above that. In our case, the stockpiles were mostly disposed above a concrete plane, of which level we determined by measuring the extremities, so we were able to find a custom level above which we made the volume computation.

In order to validate the results, we used two more software to process and compute volumes. We used Dronedeploy to reprocess all photos and determine the volumes, and we also used Global Mapper.

In Figures 8 and 9 we presented the stockpiles and volume computation using Dronedeploy.

As a third comparable value we made the volume computation in Global Mapper. For obtaining the 3D model, we generated a DEM from the point cloud exported from Agisoft Photoscan. Global Mapper computes volume dividing the surface into more sections, as it was presented before at materials and methods. In Figure 10 it can be seen a cross section in Global Mapper, and in Figure 11 the volume computation for a stockpile.

Figure 8. Stockpile 1 presented in Dronedeploy

Figure 9. Stockpile volume computation using Dronedeploy

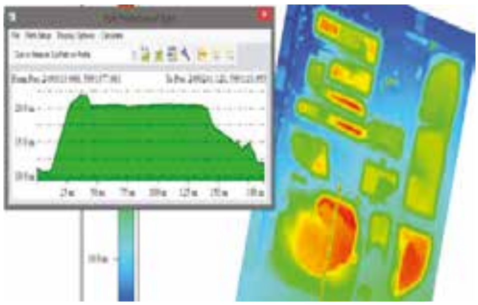

Figure 10. Cross section of a stockpile Global Mapper

Figure 11. Volume computation Global Mapper

After computing the volume using three different software, we compared the obtained results. We had differences up to 3.07%, mostly because of the vectorisation of the surface area taken into study, and the difference between applied volume calculation methods. The results are presented in Table 2.

Table 2. Stockpile 1 Volumes and differences using the three software solutions

Stockpile	1. Volume Dronedeploy [m^3]	2. Volume Agisoft [m^3]	2. Volume Global Mapper [m^3]	Difference % (1, 2)	Difference % (1, 3)	Difference % (2, 3)
S1/I	69316.486	70092.831	70711.333	1.120	1.990	0.875
S1/II	36827.770	36246.628	36540.334	-1.578	-0.793	0.804
S1/III	35549.472	35094.794	35260.642	-1.279	-0.823	0.470
S1/IV'	62481.779	63856.378	63329.792	2.200	1.328	-0.831
S1/V	37778.297	38265.259	38080.593	1.289	0.790	-0.485
S1/VI	25067.558	24727.642	24807.918	-1.356	-1.050	0.324
S1/VII	16020.473	16337.999	16189.081	1.982	1.032	-0.920
S1/VIII	225017.353	218514.351	219869.155	-2.890	-2.356	0.616
S1/IX	138740.792	134481.450	135253.688	-3.070	-2.593	0.571
S1/X	67526.297	68167.797	68173.891	0.950	0.950	0.009

CONCLUSIONS

As shown in the Table 2, there are no significant differences in volume computation by using different software.

Agisoft Photoscan computes the closest volume, comparing to Global Mapper, but Dronedeploy is more different than the others, maximum variation determined was 3.07%.

If it is to put in balance, those 3% regarding to the 138740.792 square meters is not significant at all, as per the total surface of the stockpile it would generate less than 1cm in height difference.

Comparing to classical methods, the UAV photogrammetric method is safer for the operator, and in the same time is much more cost efficient, as the measurements are made really quick. The UAV photogrammetric method, we can say it`s more accurate, as it captures all the details regarding the stockpile, it could be said that we obtain a model, stone by stone. By classical methods we never capture all the characteristic elements of the stockpile, for example small gaps or hills. we usually capture a general surface, and we just ignore the small details, as it is much more time consuming to get all the small characteristics, and in fact it doesn`t count as much in percent's regarding the whole volume.

Comparing the volume determination using UAV photogrammetric methods to the classical ones, where usually u measure a number of cross sections, and then approximate the volume by multiplying the cross sections surface with the distance between them, we can easily say that by classical methods we lose much more details than using the UAV photogrammetric method. Those details represent much more than those 3% difference from the software, thereby we can affirm that any software used is closer to reality than the classical volume computation.

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