Remote sensing and photogrammetry applications in open-pit mines and quarries

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Abstract

The purpose of the present study is revealing some aspects regarding the use of remote sensing and photogrammetry in support of current surface mining operations and mining mapping. The practical result of the paper, expressed through the case study, is materialized in obtaining the digital surface model, the digital orthophotomap and volume calculation for Mateiaş-Dealul Hulei limestone quarry in the northern part of Argeş County, Valea Mare Pravăț Village, România.

Keywords: remote sensing, photogrammetry, 3D modelling, cartography, mining survey, mining quarry.

1 Introduction. Theoretical aspects

Photogrammetry is the science and technology of obtaining reliable, metric and quality information concerning space objects, about the environment, by using processes of recording, measurement, processing of measurements and interpretation of photographic images and results obtained remotely, without physical contact with the studied object or environment, using as support of this information the electromagnetic radiation.

Remote sensing is the technical field regarding the detection, measurement, recording and visualization in the form of images of electromagnetic radiation emitted by objects and phenomena from the Earth or from outer space, from a distance, without having direct contact. Remote sensing uses a set of physics and engineering applications to capture images. The finality of this field of technology is the remote sensing image, obtained by various means. The objective character of the remote sensing images is superior to "classic" cartographic products such as the topographic plan or map in research.

Digital terrain model (DTM) represents a mathematical representation of the earth surface, an approximation of it - given that the natural relief has a complex form, it is approximated by a continuous function $H=f(N, E)$, in a three-dimensional system in which the position of a point is described by its coordinates N, E and H or, in a local system, by x, y, z coordinates. The digital terrain model is the basis of modern calculations of volumes exploited and uncovered in surface mining. The expediency of calculations recommends its use [1].

The practical applications of photogrammetry in open-pit mines and quarries are:

- 3D models such as digital terrain model (DTM), digital surface model (DSM);
- Inventory of industrial mining objectives;
- Monitoring the stability of the studied area;
- Determination of blasting surfaces using explosives;
- Pre and post blasting studies;
- Real estate management regarding the properties that will be affected by the mining project - expropriation / purchase or concession of land for mining purpose, feasibility studies;

- Longitudinal profiles determination, cross sections, necessary for the realization of the communication paths, tailing routes, optimal routes determination for the industrial drainage pipes;
- Exploited and uncovered volumes determination;
- High resolution images - orthophotomaps;
- Perspective images;
- Future guides and plans;
- Environmental impact studies;
- Water drainage management, drainage plans;
- Centralization of extracted material;
- Statistical calculations.

The use of UAV systems is appropriate when taking soil samples, required for various physical and chemical analyses or even for the rapid dispatch of spare parts in the mining perimeter [2]. Applications for the use of UAVs in the dispatch of spare parts, parcels weighing up to 30 kg, are already used in Australia, resulting in significant cost reduction [3][4].

High-resolution centimetric degree information are at the basis of specific studies, greatly reducing ”classic” land survey measurements that may lead to disruptions in the flow of mining activities in open-pit mines and quarries. Photogrammetric information is also the basis for the development of geographic information systems, present in modern mining, being the basis of a performance mining management.

Remote sensing applications in the measurements field are the recording of terrestrial surface images, objects and phenomena using electromagnetic radiation emitted by them, such as recording the solar radiation reflected by surfaces – remote sensing by optical sensors based on multispectral images, infrared reflection, or infrared radiation Thermal-remote sensing by thermal sensor, use of radiometry and the principle of satellite television. Other applications are active remote sensing using microwaves, the radar principle applied in digital relief modelling, complementary to photogrammetric images; the lidar principle with applicability in the mapping field.

Remote sensing applications in surface mining are:

- Geological models determination;
- Land lithology studies;
- Power lines integrity inspection;
- Industrial chimneys thermal scanning;
- Industrial energetic audit;
- Fire outbreaks detection.

2 Technical operations

The digital orthophotomap of the mining quarry was made in June 2017, using the senseFly eBee fixed-wing UAV system, at a flight altitude of 270m, resulting in a covered area of 447ha, in 504 color images. The obtained orthophotomap has a pixel resolution of 83mm. For easy CAD operation, the image format is *.ecw.

The SenseFly eBee UAV photogrammetric system weighs 1.1 kg, offering a nominal coverage of up to $2.2km^2$ in a single flight, wind resistance of up to 45km/h or 12m/s, 59 minutes maximum flight time, 40-110km/h or 11-30m/s flight speed, resulting multispectral images – green (550 BP 40), red (660 BP 40), red limit (735 BP 10), near infrared (790 BP 40), high resolution RGB data with Canon Ixus 127HS camera with 16 megapixel CMOS image sensor. This system performs a professional airborne mapping at a maximum resolution of 15mm/pixel, depending on the flight height, 3D maps and models up to 50mm accuracy. As compared to the usual multispectral images, a mining UAV system can be equipped with a remote sensing radiometric thermal sensor, providing thermographic information, infrared radiometer recording, applicable to high and medium voltage line inspection, fire detection, energy audit of mining industrial installations and thermal scanning of chimneys. A UAV system can also be equipped with methane gas detection sensors, useful for underground mining, and rescue missions based on the thermal information can be performed with UAV systems in the event of underground work accidents.

The flight plan was realized with the eMotion 3 software and the photogrammetric data processing was obtained with Agisoft PhotoScan Professional software. Other photogrammetric software that can be used for data processing are Pix4DMapper Pro, 3DF Zephyr Pro, Drone Deploy, ContextCapture by Bentley Company, ImageModeler, Recap, Memento, 123D Catch, software solutions offered by Autodesk company.

The coordinates for the ground markers, control and check points, were determined in Stereografic 1970 projection system and Marea Neagră 1975 reference plan. To obtain these, a GNSS receiver Hemisphere S321 was used with Real Time Kinematics (RTK) position determination system with Networked Transport of RTCM via Internet Protocol (NTRIP) and ROMPOS positioning system, provided by the National Agency for Cadastre and Land Registration in Romania.

Fig. 1 High resolution orthophotomap of Mateiaş-Dealul Hulei quarry, view in Global Mapper software

The number and position of the markers were established so they are evenly covering the study area. The coordinates were calculated through the arithmetic mean of nine successive determinations obtained with the Carlson SurvCE data collection software. The conversion from ETRS '89 system to Stereographic 1970 national system and Marea Neagră 1970 reference plan was obtained with TRANSDAT program, implemented in the data collection software.

Fig. 2 Mateiaş-Dealul Hulei limestone quarry

The necessary workflow for obtaining the orthophotomap and the surface digital model includes the following field and office stages:

- land recognition;
- establishing the limits of the study area imposed by the beneficiary;
- establishing the number and the position for the ground control points (GCP) and check points (CP);
- determining the coordinates for the landmarks by GNSS technology;
- obtaining the flight plan with eMotion 3 software, based on the study area previously determined;
- realizing the actual flight with UAV system senseFly eBee;
- downloading the data collected in the field and processing it. The photogrammetric processing was done with Agisoft PhotoScan Professional. It implied adding the images acquired in the field, calibrating the camera and aligning the images, inserting and marking the landmarks on the images, establishing the control and check points, indirect georeferencing of the image model based on ground control points, a minimum of 3 points needed as concluded in previous studies [5][6], generating the cloud point using the pixel correlation technique, generating the surface digital model, realizing the digital orthophotomap (variation errors of the field were eliminated by overlapping the image model over the surface digital model), finally exporting in the chosen format, in our case *.ecw.

- photogrammetric products internal quality check, according with the beneficiary requests – quantitative and qualitative assessment;
- delivery to beneficiary.

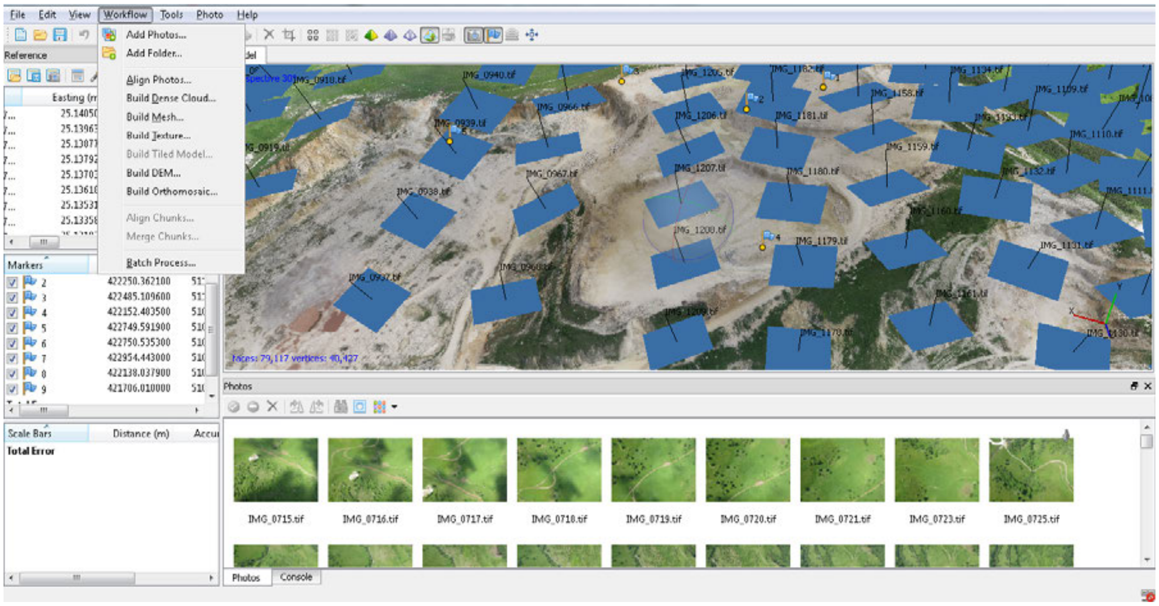

Fig. 3 Workflow menu for Agisoft PhotoScan Professional software

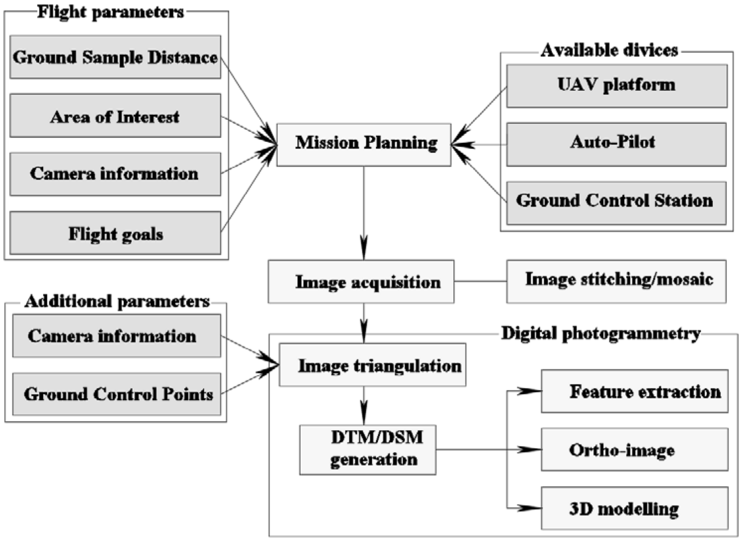

Fig. 4 General workflow for image acquisition with UAV [7]

The coordinates for the check points were graphically determined on the georeferenced image model. The difference between the check points coordinates, measured with a GNSS receiver, and the coordinates of the same points graphically determined, indicates the accuracy of the ortophotomap and DSM. This way the root mean square error was calculated using the Euclidian distance between the two coordinate sets for a point calculated with the equation:

$$RMS_{ERROR} = \sqrt{(N_{GNSS} - N_{IMAGE})^2 + (E_{GNSS} - E_{IMAGE})^2 + (H_{GNSS} - H_{DSM})^2} \qquad 1)$$

Where:

$N_{GNSS}, E_{GNSS}, H_{GNSS}$ – the coordinates of a CP obtained by GNSS measurements;

$N_{IMAGE}, E_{IMAGE}, H_{DSM}$ – the coordinates of a CP obtained by graphical measurements.

Chart 1 Check points coordinates measured with GNSS technology and graphically determined on the image

	Coordinates obtained by GNSS measurements			**Coordinates obtained by image measurement**		
Point no.	**N[m]**	**E[m]**	**H[m]**	**N[m]**	**E[m]**	**H[m]**
1	422153.878	511096.078	1024.630	422153.877	511095.998	1024.610
2	422250.362	511017.763	1024 169	422250.389	511017.718	1024.180
3	422485.110	511054.821	1017 389	422485.115	511054.772	1017.374
4	422152.484	510786.700	1001.075	422152.553	510786.630	1001.061
5	422749.592	510885.800	971.841	422749.587	510885.720	971.876
6	422750.535	510434.791	959.581	422750.496	510434.764	959.651
7	422954.443	510404.604	941.084	422954.371	510404.631	941.071
8	422138.038	510304.411	890.227	422137.977	510304.458	890.280
9	421706.010	510577 576	863.600	421706.084	510577.604	863.570

For precision analysis, the root mean square error for each of the nine check points is shown in Chart 2.

Chart 2 Accuracy analysis of check points

Point no.	**ΔN[m]**	**ΔE[m]**	**ΔH[m]**	**RMSE[m]**
1	0.001	0.080	0.020	0.082
2	-0.027	0.045	-0.011	0.054
3	-0.005	0.049	0.015	0.052
4	-0.069	0.070	0.014	0.099
5	0.005	0.080	-0.035	0.088
6	0.039	0.027	-0.070	0.084
7	0.072	-0.027	0.013	0.078
8	0.061	-0.047	-0.053	0.093
9	-0.074	-0.029	0.030	0.085

The highest errors were determined for check points 4 and 8. Considering the pixel dimension on the ground is 83 mm, we can conclude that we are in tolerance, the marking accuracy being 2-3 pixels.

For the Mateiaș-Dealul Hulei mining quarry the volume of exploited material is calculated quarterly, calculated for the mining taxes payment to the National Agency for Mineral Resources in Romania, by the licensed company to exploit limestone in the mining perimeter. This calculation is made based on GNSS measurements, terrain surface model acquisition and processing with Sierra Topko, benchmarking the previous quarter of the year. As a way of certifying the fairness of the calculation of the annually exploited volume, the exploited volume was determined between the second quarter of 2016, when the previous photogrammetric study was realized, and the second quarter of 2017, current study. Based on the digital surface model referred to the two time tables, quarter II of 2016 and quarter II of 2017, by substracting the two, the exploited volume was obtained in one year period. The value determined by photogrammetric means was close to the one resulted from the GNSS measurements done quarterly and summed, the difference being of the order of hundreds of cubic meters, thus concluding the fairness of the calculations made quarterly. The value resulting from volume calculations determined by GNSS measurements was slightly less than that obtained by photogrammetric means, being 3.46% lower in value, thus we conclude that this is normal due to the much more accurate approximation of terrestrial surface by photogrammetry than by GNSS measurements, hence resulting larger and more accurate volume in photogrammetric processing.

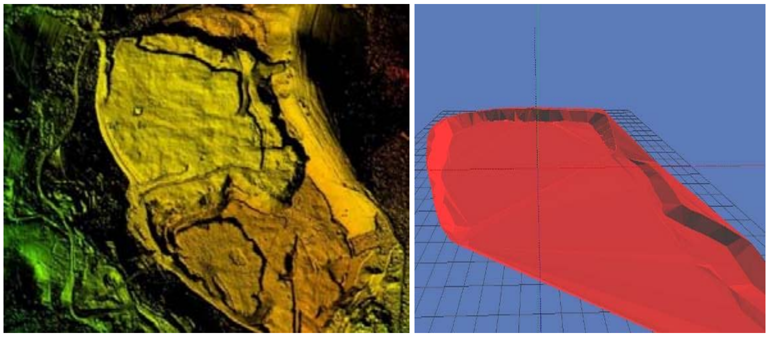

Fig. 5 Digital Surface Model concerning the quarry (left image); volume determined with reference to a working front, view in the Sierra Topko software (right image)

3 Results

This study's result is Mateiaș-Dealul Hulei limestone quarry and proximity area orthophotomap in digital format. This covers an area of 447 ha, with a ground pixel resolution of 83 mm. The digital surface model for the studied area was obtained as well the volume for the exploited material in the mining perimeter between June 2016 and June 2017. For the studied area and the purpose of the work, the digital model of the surface is sufficient, not being necessary to reduce it to the digital terrain model - in the mining work area these 3D models are identical.

4 Conclusions

In the last decade, photogrammetry based on UAV systems progressed significantly, becoming increasingly more accessible, massive research in this direction coming from both military and civil sectors. Future developing directions regard especially a growth of flight autonomy by implementing new battery technologies, increasing the payload, control and reliability facing atmospheric factors - wind, moisture, perfecting the satellite positioning systems aiming a decrease in the number of ground landmarks, a decrease of the general cost for accessing the technology, including the hardware part, but also the software products used in photogrammetric processing. All these result in utilising, on a greater scale, the photogrammetry based on UAV systems and a diversification for the applications where it is used.

Advantages in using the photogrammetric technology and remote sensing in mining exploitation:

- the field stage is realised rapidly, during a day or even a few hours;
- high accuracy;
- the personnel involved in the measurement stage is relatively low;
- studying isolated areas, areas that cannot be accessed in any other way - inaccessible areas, with high risk of caving in, inadequate for classic measurements;
- acquiring data in the visible spectrum, but also in the invisible one, infrared IR, for example;
- supplying global data regarding spread out areas concerning the ecological impact on the environment.

Disadvantages in using the photogrammetric technology and remote sensing in mining exploitation:

- rather high costs - at this moment being feasible only for medium and major projects, disadvantage that is gradually overcome by new technology;
- highly qualified personnel, resulting in high human resource costs;
- dependency on atmospheric conditions for the photogrammetric flight;
- expensive equipment for data processing, interpreting and manipulating it;
- marking a high number of ground points - lately this inconvenient has been surpassed, the modern UAV systems being equipped with GNSS receivers which allow the perception of the correlations in real time, resulting in an accurate determination of the coordinates for the perspective centres and the possibility of integrated orientation of the sensors (ground check points + coordinates of perspective centre) or direct georeference of the image model (using only the coordinates of the perspective centres).

REFERENCES

[1] C.S. Manu, I. Boroica, D.F. Tivig, M.C. Costea Digital Terrain Model In Mining Topography Applications, RevCad no. 22/2017 Aeternitas Publishing House Alba Iulia, ISSN 2068-519X

[2] https://www.expouav.com/wp-content/uploads/2016/03/free-report-uavs-for-mining-and-aggregate-operations.pdf

[3] http://www.abc net.au/news/2012-04-30/drones-to-conduct-mine-aerial-surveillance/3979732

[4] https://www.cio.com.au/article/539451/firefighting_mining_sectors_see_future_drones/

[5] Oniga E., Chirila C., Macovei M. Low-cost unmanned aerial systems in cadastral applications. SGEM2016 Conference Proceedings, ISBN 978-619-7105-59-9 / ISSN 1314-2704, June 28 - July 6, Book2 Vol. 2, 947-954 pp, 2016.

[6] Tahar K. N. An evaluation on different number of ground control points in Unmanned Aerial Vehicle photogrammetric block. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XL-2/W2, 2013

[7] Nex, F. C., & Remondino, F. (2014). UAV for 3D mapping applications: a review. Applied geomatics, 6(1), 1-1-2015. DOI: 10.1007/s12518-013-0120-x