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TLS AND LOW-COST UAV PHOTOGRAMMETRY AS AN EFFECTIVE COMBINATION OF SPATIAL DATA COLLECTION METHODS FOR CREATING DETAILED 3D SURFACE MODELS (DEM)

Abstract: The development of surveying methods and equipment has moved from conventional surveying methods to modern technologies such as Unmanned Aerial Vehicle (UAV) aerial photogrammetry or Terrestrial Laser Scanning (TLS). Our research deals with the comparison of spatial data obtained by these methods in the surface quarry Dreveník, Slovakia. Point clouds obtained by both methods were compared using CloudCompare and Leica Cyclone 3DR software. The mean absolute distance of the point clouds was 2.02 cm and the standard deviation between point clouds was 2.48 cm. Our results confirmed the compatibility and the possibility of combining point clouds.

Keywords: TLS, UAV, SfM photogrammetry, geohazard, point cloud, open-pit quarry

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Introduction

The development and application of modern surveying techniques can speed up, refine and simplify the process of obtaining spatial data about objects. One of the most advanced methods is photogrammetry using the Structure-from-Motion processing approach, which produces 3D models and orthophotos with high accuracy and detail. A current trend is the use of aerial photogrammetry, where a camera is mounted on an unmanned UAV. This approach is particularly suitable for smaller areas due to its ease of use, low acquisition costs, speed of data collection and high accuracy of terrain models, and it has become a suitable alternative in terms of quality and efficiency compared to conventional surveying methods. Surveying using UAV technology has been applied in various fields and disciplines such as mining (Park & Choi, 2020; Ćwiąkała et al., 2020), cadastre (Šafář et al., 2021; Fetai et al., 2019), industry (Ajayi et al., 2021; Kovanič et al., 2021), geology (Blišťan et al., 2016; Jacko et al., 2021), archaeology (Fiz et al., 2022; Schroder et al., 2021; Marčiš et al., 2023), architecture (Lin & Sang, 2022; Germanese et al., 2019), agriculture (Lambertini et al., 2022; Marín-Buzón et al., 2020) or for monitoring natural processes in the landscape such as slope stability (Migliazza et al., 2021; Junaid et al., 2022), geohazards (Kovanič et al., 2020; Urban et al., 2019) or landslides (Kyriou et al., 2021; Gantimurova et al., 2021).

Terrestrial laser scanning (TLS) is used to survey objects and small landscape areas. TLS is characterized by high speed of measurement and high point density. It is used to measure the positions and shapes of various asymmetric and irregular objects and features. With sufficient detail, speed and number of points, creating an accurate 3D digital model of a non-uniform object of varying size and shape is possible. TLS uses the spatial polar method principle to determine the points' spatial coordinates. The application of TLS is in the fields of structural design (Bariczová et al., 2021; Erdélyi et al., 2020), engineering and industry (Sofranko & Zemen, 2014; Wittenberger & Sofranko, 2015; Kovanič et al., 2020; Kovanič et al., 2023) or mapping (Pukanská et al., 2020).

Ground control points are commonly used to georeference TLS and photogrammetric models (Ren et al., 2020). In photogrammetry, GCPs are also used to correctly determine the elements of the internal and external orientation of the camera. GCP coordinates are determined in the field by direct measurement, e.g. using total stations or GNSS receivers. GCPs for georeferencing photogrammetric data have been used by (Vanneschi et al., 2019; Cao et al., 2019; Wallace et al., 2016; Štroner et al., 2021; Tomaštík et al., 2019). Acquiring photogrammetric data without GCPs is possible if a UAV with RTK/PPK is used. In this case, the use of checkpoints is recommended. The authors have addressed measurements without using GCPs (Štroner et al., 2020; Zeybek, 2021; Salach et al., 2018; Forlani et al., 2018).

The most common outputs from non-contact data collection are aerial photographs, digital models (Kovanič et al., 2021; Kovanič, 2013), digital surface models, digital elevation models, point clouds, vector maps or orthophoto maps (Santagara, 2017; Kunina et al., 2018; Puniach et al., 2018) representing real-world objects.

Material and methods

The site chosen for this work was the Dreveník quarry, located in the cadastral area of Spišské Podhradie near the village of Spišské Podhradie (Fig. 1) in the eastern part of the Slovak Republic. The town is located in the Hornád basin in the valley of the Margecianka river, about 12 km east of Levoča (Spišské Podhradie, 2023; Úrad geodézie, kartografie a katastra SR, 2023; Univerzita Komenského v Bratislave, 2023).

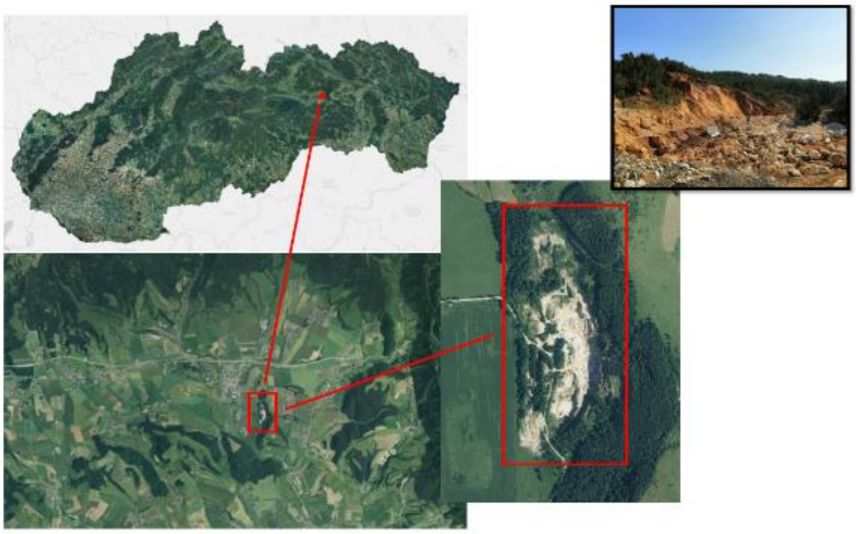

Fig. 1. Location of the Dreveník quarry
Source: Own elaboration

Entire quarry and its surroundings have been on the state list of specially protected natural sites in the Slovak Republic since 1925. The quarry was formed by joining several travertine piles deposited here from mineral springs and is part of the National Nature Reserve. It is located in the Hornádská Basin on the border of the districts of Spišská Nová Ves and Levoča. It has been on the World Heritage List of the United Nations Educational, Scientific and Cultural Organisation (UNESCO) since 1993. The Slovak Paradise National Park administers the national nature reserve and is in the highest fifth level of protection. Dreveník is one of the largest and oldest protected areas of karst morphology in Slovakia. It is essential as a cultural and natural monument and for its travertine quarries.

Surveying equipment. GNSS rover Leica GS07. Nowadays, thanks to GNSS technology, high-precision positioning anywhere on Earth is already available. It's simple real-time operation is widely used in surveying, mapping and other applications. The Leica GS07 (Fig. 2) is a lightweight and compact Leica Geosystems instrument consisting of a Smart Antenna, a Leica CS20 controller and a telescopic boom. Thanks to the adaptive satellite selection. All other specifications related to the instrument are listed in a clear table (Table 1) (Geotech s.r.o., 2023).

Fig. 2. GNSS rover Leica GS07
Source: Geotech s.r.o., 2023

Table 1. Specification of GNSS rover Leica GS07

Technology	Leica RTKplus	
Weight	2,85 kg	
Channels	320	
SmartCheck	Continuous monitoring of the RTK solution	
Initialization	6 sec	
RTK accuracy	Single base	Horizontal: 10 mm + 1 ppm
		Vertical: 20 mm + 1 ppm
	Network RTK	Horizontal: 10 mm + 0,5 ppm
		Vertical: 20 mm + 0,5 ppm
Post-processing	Static long observation	Horizontal: 3 mm + 0,5 ppm
		Vertical: 6 mm + 0,5 ppm
	Static and fast static	Horizontal: 5 mm + 0,5 ppm
		Vertical: 10 mm + 0,5 ppm

Source: Own elaboration based on: Geotech s.r.o., 2023

Surveying equipment. Terrestrial laser scanner Leica RTC 360. The Leica RTC360 laser scanner (Fig. 3) from Leica Geosystems is a mobile, automated and efficient 3D laser scanner with a range of up to 130 m. It can reliably and accurately scan everything around the instrument in a short time interval. As a result, a colored point cloud of millions of points is obtained. Automatic registration in the field using VIS technology is also a significant advance, reducing processing time. Specifications and technical parameters are shown in Table 2. During the measurement, the laser scanner is placed on a fixed-head carbon tripod consisting of three telescopic legs (Geotech s.r.o., 2023).

Fig. 3. Terrestrial laser scanner Leica RTC 360
Source: Geotech s.r.o., 2023

A new feature is double scanning, which automatically removes moving objects, whether indoors or outdoors. An integrated large colour touchscreen or a mobile phone or tablet can control the device. The Leica Cyclone FIELD 360 app, designed to view and control the data acquired by the laser scanner, works quickly and easily. The practical application of the device is versatile, whether in industry, surveying or the civil sector (Geotech s.r.o., 2023).

Table 2. Specifications and technical parameters
of Terrestrial laser scanner Leica RTC360

Technology	3D laser scanner with integrated system for capturing HDR panoramic images and VIS (Visual Inertial System) for real-time cloud data registration		
Data acquisition	< 2 minutes for full scan and HDR panoramic image at 6mm @ 10m scan resolution		
Weight	5,35 kg (without batteries)		
Scanning	Double scanning	Automatic removal of moving objects	
	Scanning speed	2 000 000 points/sec	
Accuracy	Angle	18"	
	Distance	1,0 mm + 10 ppm	
	3D point	1,9 mm @ 10 m	
		2,9 mm @ 20 m	
		5,3 mm @ 40 m	
Camera	Quality	36 MPx	3-camera systém
		432 MPx	Raw data for calibrated 360° x 300° panoramic image
	Capturing speed	1 minute for 360° HDR panoramic image in any lighting conditions	
Range	0,5 m – 130 m		
Resilience	IP54		
Working temperature	- 5°C až + 40°C		
Storage temperature	- 40°C až + 70°C		

Source: Geotech s.r.o., 2023

Surveying equipment. UAV DJI Phantom 4 RTK. Thanks to modern and constantly evolving times, it is possible to collect large amounts of data even from the air in the required quality and in a short time interval. The DJI Phantom 4 RTK UAV (Fig. 4) is a compact, precise, fast UAV operating at low altitudes. The DJI Phantom 4 RTK is controlled using a controller with an integrated display by the DJI GS RTK app. The device is controlled by a trained pilot safely on the ground. Using an integrated RTK module, this UAV provides centimetre accuracy in the flight. Precise coordinates are used in post-processing. At the bottom, a 20 MPx camera mounted on a gimbal captures images or video.

Further specifications of the device can be seen in Table 3. With these features, the manufacturer provides a spatial resolution (GSD) of only 2.74 cm at a flight height of 100 m at high-resolution imaging. Combining RTK image files and proper georeferencing using the SfM processing method allows detailed three-dimensional (3D) models and point clouds to be reconstructed with centimetre-level accuracy (DJI, 2023).

Fig. 4. UAV DJI Phantom 4 RTK
Source: DJI, 2023

Table 3. Technical parameters of UAV DJI Phantom 4 RTK

Aircraft	Weight	1391 g	
	Max. speed	Ascending	6 m/s
		Descending	3 m/s
		Flight	50 km/h (mode P) 58 km/h (mode A)
	Max. time of flight	cca 30 min	
Accuracy	active RTK	Horizontal	± 0,1 m
		Vertical	± 0,1 m
	Non-active RTK	Horizontal	± 0,3 m
		Vertical	± 0,1 m
Camera	Senzor	1" CMOS	
	Quality	20 MPx	
	Size of image	4864 × 3648 (4:3)	
	Angle	- 90° to + 30°	
GNSS	GPS, BeiDou, Galileo, GLONASS		
Batteries	Type	LiPo 2S	
	Kapacity	4920 mAh	
	Voltage	17,5 V	

Source: Own elaboration based on: DJI, 2023

Fieldwork. GCP for UAV photogrammetry. During the on-site reconnaissance, 23 temporarily stabilized GCPs were placed directly in the field. Their types and location can be seen in Figure 5. Thus, the GCPs uniformly placed throughout the area play an essential role in the survey, as they are used to georeference the point clouds to a reference coordinate system or check of RTK/PPK georeferencing. For expediency, two types of targets were used, one represented by a black and white circular target and the other circular designed by the authors.

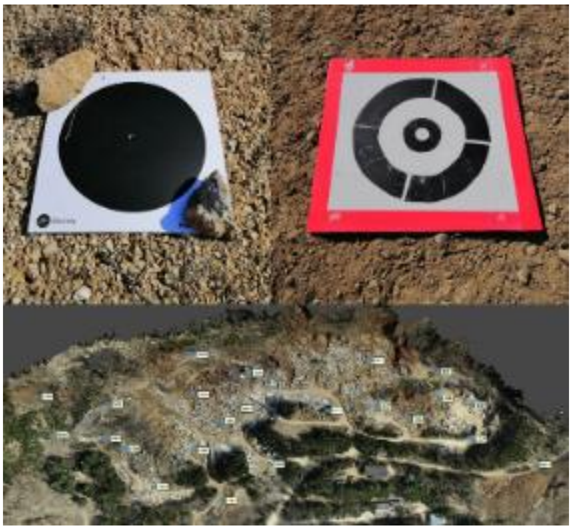

Fig. 5. GCP for UAV photogrammetry
Source: Own elaboration

Fieldwork. GCP for TLS surveying. For the TLS surveying, 11 temporarily stabilized GCPs were evenly distributed on the site. Their location can be seen in Fig. 6. For this measurement, Leica GZT21 HDS 4.5″ black and white circular scanning targets (Fig. 6) placed on pillar pads were used. The position of these targets was also surveyed by GNSS Leica GS07.

Fig. 1. GCP for TLS surveying
Source: Own elaboration

Fieldwork. UAV photogrammetric surveying. UAV DJI Phantom 4 RTK was used to capture the terrain from a height. Surveying over the 60,000 m^2 site was carried out in four separate flights. All flights were conducted using flight plans created in the Pix4D app from an average flight altitude of 70 m AGL. The camera positions during the acquisition of photogrammetric data are shown in Fig. 5. During the first flight, 430 images were captured, the second flight captured 285 images, the third captured 356 images, and the fourth captured 175 images. A total of 1246 images were captured. The image overlap was set to 70%, camera tilt was set to 80°. The total flight time was approximately 2.5 hours. Image processing was performed in the Agisoft Metashape Professional software. The acquired point cloud was georeferenced to the coordinate system using GCPs.

Fig. 7. UAV mission plan
Source: Own elaboration

Fieldwork. TLS surveying. TLS surveying was performed using a Leica RTC360 laser scanner mounted on a tripod made of carbon fibre. The measurements were performed at 19 positions (Fig. 8) with a total measurement time of about 1 h. The area of the scanned site was 14,000 m^2. For each site, 3 temporary GCPs were assigned. The scanner resolution was set to medium density at all sites with a point density of 2.9 mm at 20 m. The function for automatic removal of moving objects offered by the scanner was switched off to reduce the time. Processing with automatic GCP detection and registration was performed in the Leica Cyclone REGISTER 360+ software environment. The data processing time in the software took 2 hours.

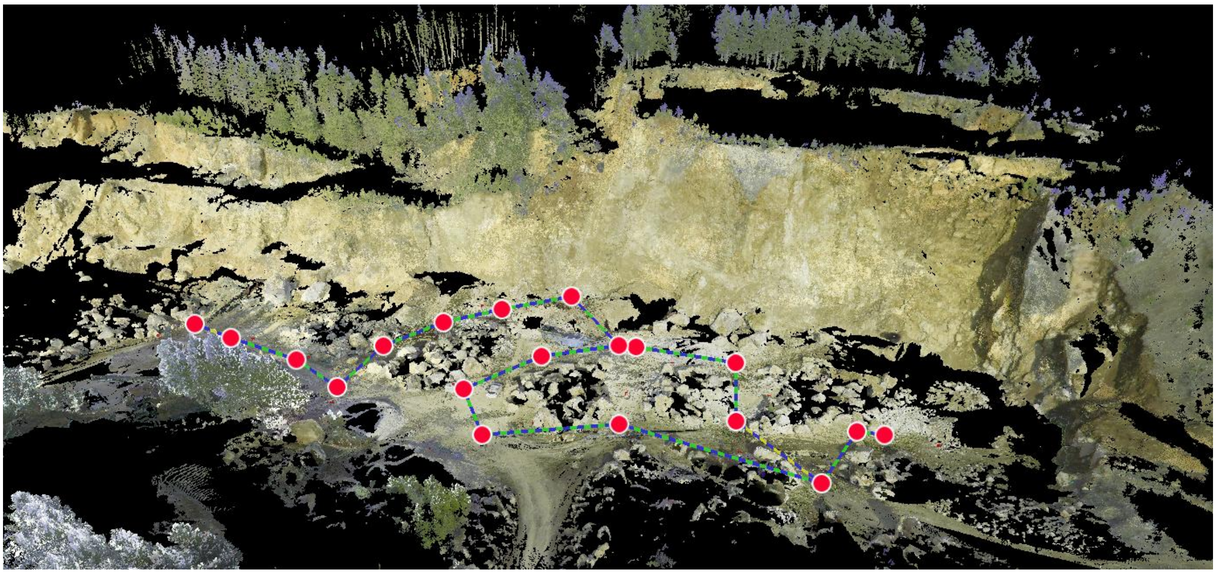

Fig. 8. Positions of the laser scanner in the TLS method
Source: Own elaboration

Data processing. SfM Processing of UAV Photogrammetry. The UAV photogrammetry produced a point cloud with a density of 85,416,175 points for the entire site. The medium quality of dense point cloud generation was chosen from 1246 images using the SfM method in Agisoft Metashape Professional software. The spatial resolution (GSD) on the processed model was 0.018 m/pix. The average point density at this location was 200 points/m^2. The root mean square positional error (RMSE) was determined with a value of 0.027 m. After filtering unwanted points, the point cloud comprised 178,805 points. Only a part of the quarry wall, with its rugged terrain, was selected from the entire site. From the processed point cloud, a digital terrain model (DTM) was created and displayed in a Smooth visualization style using CloudCompare and Leica Cyclone 3DR software, where an extraction grid size of 0.05 m was specified for GRID. CloudCompare software processing resulting in the Hillshade visualization style DTM. Another approach to data processing using Leica Cyclone 3DR software resulted in the Grey visualization style of DTM. Created Digital Elevation Model (DEM) has a resolution of 0.071 m/pix resolution DEM.

Data processing. TLS data processing. The TLS method produced a point cloud of 409,735,649 points for the entire scanned area, with a total cloud overlap of 74% and a strength of 78%. The bundle error was 0.007 m, and the cloud-to-cloud error was also 0.007 m. The root mean square position error value (RMSE) was determined with a value of 0.018 m. The average point density at this location was 8,546 b/m^2. After filtering unwanted points, the point cloud consisted of 5,636,499 points. As with the UAV, only a part of the quarry wall with its rugged terrain was selected from the entire area. The resulting DTMs were created in the same way as from the UAV photogrammetry.

Results and discussion

In this area, vegetation removal was necessary before data processing, as its presence biases the results. The Trimble Realworks 10.0.4 software was used to classify the point clouds from the UAV photogrammetry and TLS methods. Each method's shortcomings become apparent when the resulting model is inspected in more detail. For this site, the deficiencies (Fig. 9) were due to insufficient visibility, point density and dark spots. The first such example is a sample (a), where the points were not generated due to the obscuring of this location when captured from a height of 70 m AGL.

Consequently, the SfM method failed to produce a point cloud at these locations, and there are holes in the overall point cloud. The SfM method did not have sufficient visibility, and on account of this, the points formed very sparsely in places, almost not at all. In demonstration (b), the laser scanner did not sufficiently reach spots in the ground laser scanning. The locations were hidden – out of sight of the scanner, resulting in a sparse point cloud formation.

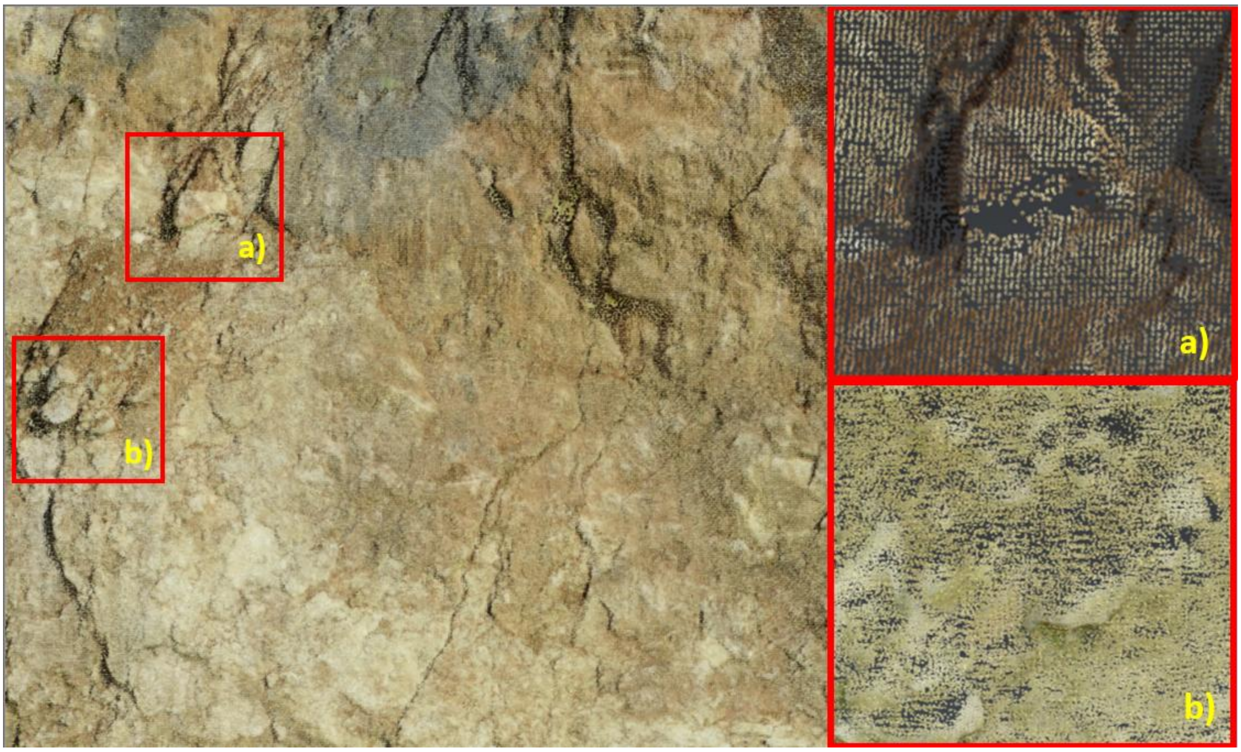

Fig. 9. Point cloud with specific comments on the completeness
Source: Own elaboration

For comparison and evaluation, DTMs (Fig. 10) of the selected section were created and processed using CloudCompare and Leica Cyclone 3DR software. The same parameter was specified for each model for an extraction grid size of 0.05 m. The detail of the models is dependent on the density of points. Their compatibility can be assumed by visually comparing the TLS and UAV data.

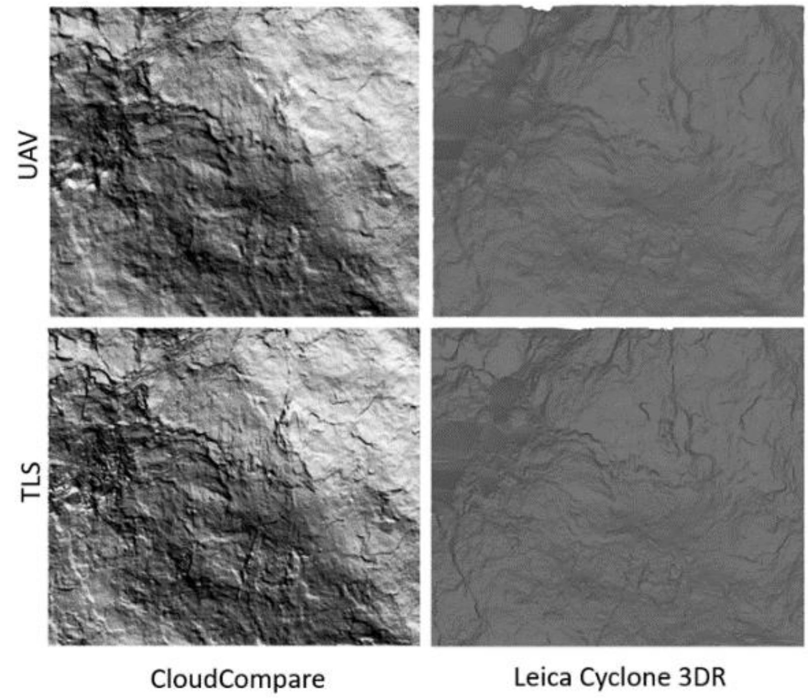

Fig. 10. DTM – TLS a UAV photogrammetry
Source: Own elaboration

The UAV and TLS point clouds were compared based on distance (Fig. 11) using the Leica Cyclone 3DR software using the Inspect Cloud vs. Cloud tool. A part of the quarry wall was selected. The maximum distance was set to 0.05 m for all comparisons. The plot shows that most points (22.7%) were located at a distance of 0.019 – 0.025 m. Overall, the most significant errors came out at locations with insufficient overlap between the two clouds due to low point cloud density or incomplete vegetation removal.

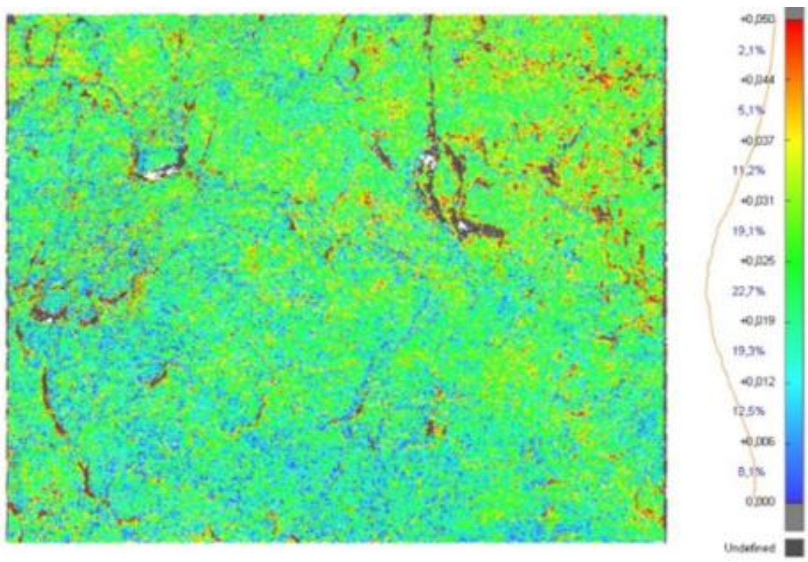

Fig. 11 Differential model – TLS and UAV photogrammetry point clouds
Source: Own elaboration

Compared were point clouds obtained by the photogrammetric method against the point cloud produced by the TLS method. This comparison was performed in CloudCompare and Leica Cyclone 3DR software. In Leica Cyclone 3DR, it can be observed that the most significant representation of points is between 0 and 3 cm and the percentage of points at error values. The CloudCompare program calculated the mean absolute distance, which gives the systematic displacement of each cloud and the standard deviation of the differences. The mean absolute distance of the point clouds is 0.0202 m, and the standard deviation is 0.0248 m. The standard deviation value was affected by incomplete vegetation removal, incomplete point cloud TLS, flight height and geometry in UAV photogrammetry, point cloud generation, etc.

Conclusions

Based on our results, it is appropriate to state that the point cloud parameters obtained by photogrammetric methods are qualitatively, accurately and comparable to the point cloud parameters obtained by terrestrial laser scanning, and both methods are thus suitable as a basis for systematic monitoring of natural or artificial objects. The advantage of the TLS method is a significantly higher point density and a better representation of the terrain in creating the DTM. However, using photogrammetric methods is preferable to using TLS due to the ease of data acquisition, flexible and quick use, cheap acquisition and equipment cost and high point cloud density. In contrast, for TLS, the equipment costs and risk of damage to expensive instruments are higher. Combining TLS and photogrammetric measurements can be considered mutually compatible and recommended as a suitable solution for documenting spatial objects.

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