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COMPARATION OF PHOTOGRAMMETRY AND TERRESTRIAL LASER SCANNING METHODS FOR EROSION MONITORING IN THE AREA OF DEVIL'S TOWN: PROJECT "DEMONITOR"

Abstract

Project "Devils' town Erosion MONITORing - DEMONITOR" involves the monitoring of accessible earth pillars in the area of Devil's town, by using a combination of several non-invasive methods. Terrestrial laser scanning (TLS) and photogrammetric imaging with unmanned aircraft (UAV) as a platform showed as great solutions for 3D modeling of this site and erosion monitoring. In this work it is shown that using manual free flight mode for imaging with UAV gave much better results than the missions performed with predefined flight plans. The desired long-term effect from this research should have a significant part in the overall socioeconomic development of the municipality of Kuršumlija, and the entire Toplica district.

Keywords: earth pillars, 3D model, photogrammetry, laser scanning

ПОРЕЂЕЊЕ МЕТОДА ФОТОГРАМЕТРИЈЕ И ТЕРЕСТРИЧКОГ ЛАСЕРСКОГ СКЕНИРАЊА ЗА ПРАЋЕЊЕ ЕРОЗИЈЕ НА ПОДРУЧЈУ ЂАВОЉЕ ВАРОШИ: ПРОЈЕКАТ „ DEMONITOR“

Сажетак

Пројекат "DEMONITOR" подразумијева праћење приступачних земљаних стубова на подручју Ђавоље вароши комбинацијом неколико неинвазивних метода. Терестричко ласерско скенирање и фотограметријско снимање коришћењем беспилотне летјелице као платформе показала су се као одлична рјешења за 3Д моделирање овог локалитета и праћење ерозије. У овом раду је показано да је коришћење ручног режима мануелног летења за фотограметријско снимање дало много боље резултате од мисије која се обавља са унапријед дефинисаним планом лета. Жељени дугорочни ефекат овог истраживања требало би да има значајан удио у укупном друштвено-економском развоју општине Куршумлија, али и Топличког округа.

Кључне ријечи: земљани стубови, 3Д модел, фотограметрија, ласерско скенирање

1. INTRODUCTION

The DEMONITOR project focuses on monitoring a rare geological marvel at the “Devils’ town” site near Prolom Spa in southern Serbia (Fig.1). This site features approximately 200 tall rock pillars, known colloquially as “the Devils”, formed by the interplay of erosional forces and volcanic rock. These pillars are the result of ages of weathering and erosion.

The project aims to monitor these pillars and surrounding weather conditions using advanced non-invasive methods such as terrestrial laser scanning (TLS), aerial photogrammetry with unmanned aerial vehicles (UAV), satellite radar interferometry (InSAR), and geophysical techniques over a three years period to quantify changes like erosion rate, rockfall occurrence, and ground subsidence.

This project is a follow-up of the pilot project MEĐA, which was realized by a part of DEMONITOR’s research team in a period of 2017-2018 [1]. During that project, two acquisitions of the test site were performed in November 2017 and November 2018 (using TLS and UAV methods). With first acquisition a so-called zero state model was produced as a 3D representation of the initial terrain surface, while each subsequent acquisition produced a new point cloud with the same characteristics in terms of reference system, resolution, and precision. By comparing the new 3D model with the previous, the spatial differences that occurred between two acquisition epochs as consequence of erosion of a pillar can be picked up and measured [2]. Newest acquisition was performed as a part of project DEMONITOR in February 2024.

For the needs of this paper, only results collected with TLS and UAV photogrammetry will be discussed because till now only these methods were used for monitoring mentioned area. Both methods give a point cloud as a result - i.e. three-dimensional model of the surface represented by high resolution points with the corresponding 3D coordinates. Model generation for these methods is different because laser scanning produces a point cloud directly, while optical imaging requires photogrammetric processing to generate a point cloud [3]. Resolution and accuracy of a point cloud is higher in the case of TLS technology [4], which allows the monitoring of the earth pillar erosion at a cm level [5], while photogrammetrically recorded images can be used for 3D modeling of the area of interest, but these results were not reliable for erosion monitoring. Another difference is in the point of view, because TLS is suitable for capturing the details on the pillars’ sides, from the ground in multiple positions, while by using UAV as a platform for photogrammetric imaging, it is possible to perform imaging above the pillars and get better approach to some hidden spots, such as shadowed objects that are inaccessible from the perspective of the scanner. These point clouds can be combined in order to generate a unique surface model, which will benefit from advantages of both source clouds – level of detail obtained with TLS and measured inaccessible areas by using UAV photogrammetry.

It is expected that results of the DEMONITOR project will not only portray the change, but also allow prediction of the change rate and trend, entailing design of appropriate prevention or stabilization measures, ultimately leading to the permanent site’s conservation. All scientific findings will be used to promote and credit the site, especially in UNESCO context, while improving its touristic value, which might further entail benefits for the local economy.

2. STUDY AREA

Devils’ town, a rare geomorphological and geological phenomenon and protected natural heritage site in southern Serbia, features nearly 200 rock pillars, some towering up to 15 m tall and 6 m in diameter, formed over years by erosional forces. The site is part of the Lece volcanic complex, showcasing a unique combination of volcanic genesis and erosion. These pillars, known colloquially as "the Devils" hold geological evidence of past volcanic activity, including violent eruptions that produced pyroclastic flows. The erosion process, influenced by various factors, continues to shape and change (collapsing, sinking and emerging) these remarkable landforms, prompting intrigue into their future amidst climate change.

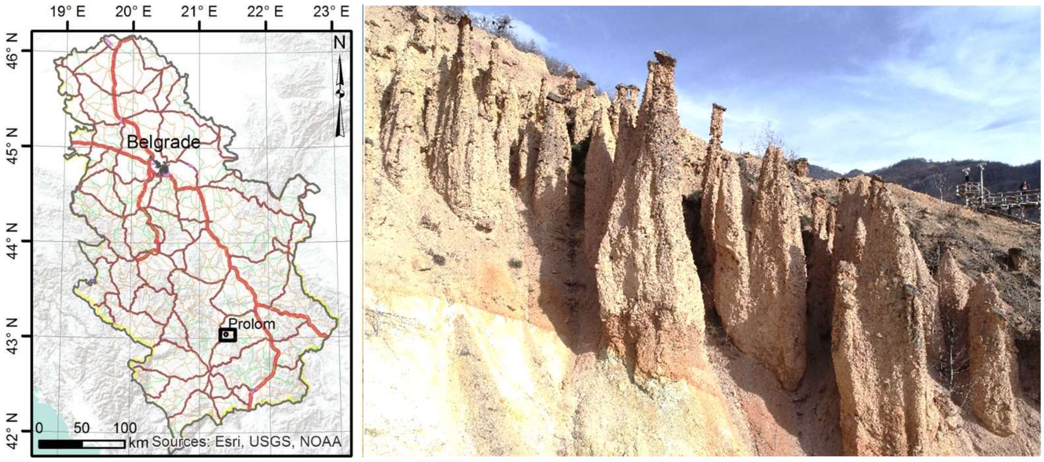

Figure 1. Devils' town location in Serbia (left) and its landforms – earth pillars (right)

3. CONCEPT AND METHODOLOGY

For the needs of this project, TLS and UAV methods will provide high-resolution local surface models, while InSAR will be used to monitor displacements of fixed ground control points (corner reflectors, and possibly strong natural reflectors, such as caprock), ensuring that the global stability of the site is satisfied, i.e., that the changes are relative to the pillars and not the wider terrain deformations, such as regional subsidence for instance. Currently, TLS and UAV approaches are used for collecting data in soil erosion monitoring [6]-[8]. UAV photogrammetry aka structure-from-motion (SfM) method using UAV imagery is a beneficial tool for topographic data collection.

It was planned to have at least two TLS and UAV acquisition sequences, i.e., two site visits, per year. Both visits are scheduled for the non-vegetative part of the year, which coincides with the touristic low season (late autumn/early spring), in order to minimize possible noise introduced by vegetation and visitors. Each sequence of scanning/imaging will produce current surface model (3D point-cloud) of the major landforms. The principal idea is to compare these surface models in appropriate software package such as CloudCompare [9], which will allow interpretation, i.e., detection and quantification of the 3D surface change between consecutive sequences (or any other combination of sequences). In plain words, it would be possible to visualize which parts of the pillars have changed between two visits and for how much.

The TLS and UAV acquisition methods are capable of capturing sub-cm changes and indicate locations that are prone to weathering and collapsing. Therefore, it is expected that pre-failure deformations can be also registered and linked to the subsequent stability models.

The software solution Agisoft Metashape [10] was used to generate point clouds with UAV data. It represents an advanced solution for 3D modeling based on images, which aims to generate high-quality 3D content from images. The images can have any position, but under a condition that the object to be reconstructed is visible in at least two images. Image alignment and 3D model reconstruction are fully automated.

Data collection using photogrammetric methods requires several stages. The first phase is flight preparation, which includes the creation of flight plan and defining the GCP (Ground Control Points) project. The flight plan is defined in such a way as to ensure the minimum overlap between images (transverse 80%, longitudinal 80%), the number of flight lines and number of images within each line. GCP project includes markers that were used for terrestrial laser scanning method, which evenly cover the entire site area. The GCP coordinates were determined by post-processing the data collected with terrestrial laser scanning in the local coordinate system. The scanner registers data in its unique coordinate system.

In MEĐA project, all of the flight missions for UAV photogrammetry were performed in a way to cover whole area of the interest with a sufficient number of overlapping images needed for 3D reconstruction. These images were usually close to nadir and collected from above on a height of 50m or 80m above the ground. The imaging was double routed, using longitudinal and transverse flight direction. In the first acquisition of the DEMONITOR project, imaging was performed manually during free flight mission which offers greater coverage of complex objects such as these landforms. In this way, much more images were collected during this type of flight but a higher level of detail was acquired with smaller number of shadowed objects (Fig. 2).

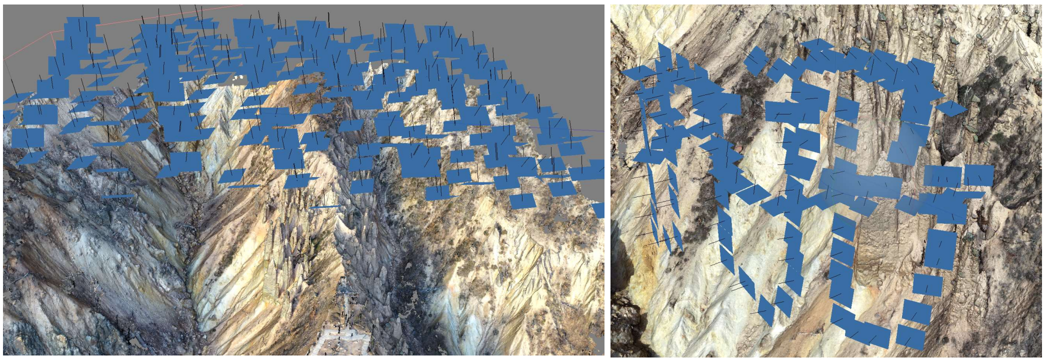

Figure 2. Two ways of mission planning – automated flight mission plan from a height of 50m (left) and free flight manual mission plan from a distance under 20m (right)

From this analysis it is obvious that in order to obtain greater detail using a UAV, a lower flight height should be achieved and the object of interest should be flown over and photographed from all sides, in order to collect as many points as possible and obtain higher detail.

4. RESULTS AND DISCUSSION

The first field work in MEĐA project was conducted in November 2017. The first results of the erosion calculation were obtained after the second acquisition, which was performed in November 2018. Time period between missions was not long enough for the detection of noticeable changes of earth pillars.

First field work in DEMONITOR project was conducted in February 2024. The TLS scanning took about 3.5 hours, while UAV imaging with lasted about one hour and 30 minutes with three batteries used. Terrestrial laser scanner used was Leica ScanStation P20 while available UAV used for photogrammetric mission was DJI Phantom 4 PRO. This aircraft has a 20Mpix camera with mechanical shutter which makes this UAV camera more suitable for photogrammetry needs. Real field conditions caused that certain parts of the area remained inaccessible for scanning and imaging, for example, between the closely positioned pillars, which shadowed one another. Also, there were areas behind these landforms that were not accessible for measuring. A local coordinate system was set up for LiDAR scanning process, while a total of 10 surveying marks were used as tie points for linking successive scans from different stations, and these points were also used as GCP points for georeferencing photogrammetric block of aerial images.

A total of 680 images were recorded from a distance of 20 m from earth pillars resulting in image generation at each 2 m of traveled way that gives sufficient image overlap between consecutive image locations (> 80%). The recording included an area of 0.047 km2. The mean total error of the resulting point cloud was about 2.6 cm. For the creation of a dense point cloud with high qualty option, 48.1 million points were generated. Comparison with UAV missions performed in 2017 and 2018 is presented (Table 1).

Table 1. Results comparison of each UAV mission

Epoch	Number of images	Number of points	GCP total error [cm]	Processing time [h]
2017	254 (80m height)	15,8 million	1.0	16
2018	424 (182 at 50m and 242 at 80m height)	31.3 million	1.1 (50m) 2.9 (50m+80m)	20
2024	680 (20m distance)	48.1 million	2.6	26

Finally, an orthophoto with resolution of 2 cm/pix was obtained while reconstructed digital elevation model's resolution was 4 cm/pix.

As it can be seen from the results, 3D point cloud generated using photogrammetric processing of imagery collected in 2024 showed much greater detail when comparing with 3D point clouds obtained from mission performed in 2018. This is obviously the result of using a new imaging procedure with free flight manual mission plan that also gives higher spatial resolution. Also with this type of analysis, rockfall occurrence is possible to identify (Fig. 3).

Figure 3. Difference between level of detail between 3D model reconstructed with automated mission flight plan (left) and free flight manual mission flight plan (right)

By visual comparison, it was concluded that the point cloud obtained by the UAV system has a lower resolution than the cloud of points obtained by the TLS method. We observed the details of one pillar, called “Barjaktar”. Upon observation of the “Barjaktar” figure, it can be concluded that a significant number of details, such as small pebbles and rocky outcrops, are missing in the point cloud obtained by the UAV system, whereas they are clearly indicated in the TLS method (Fig. 4).

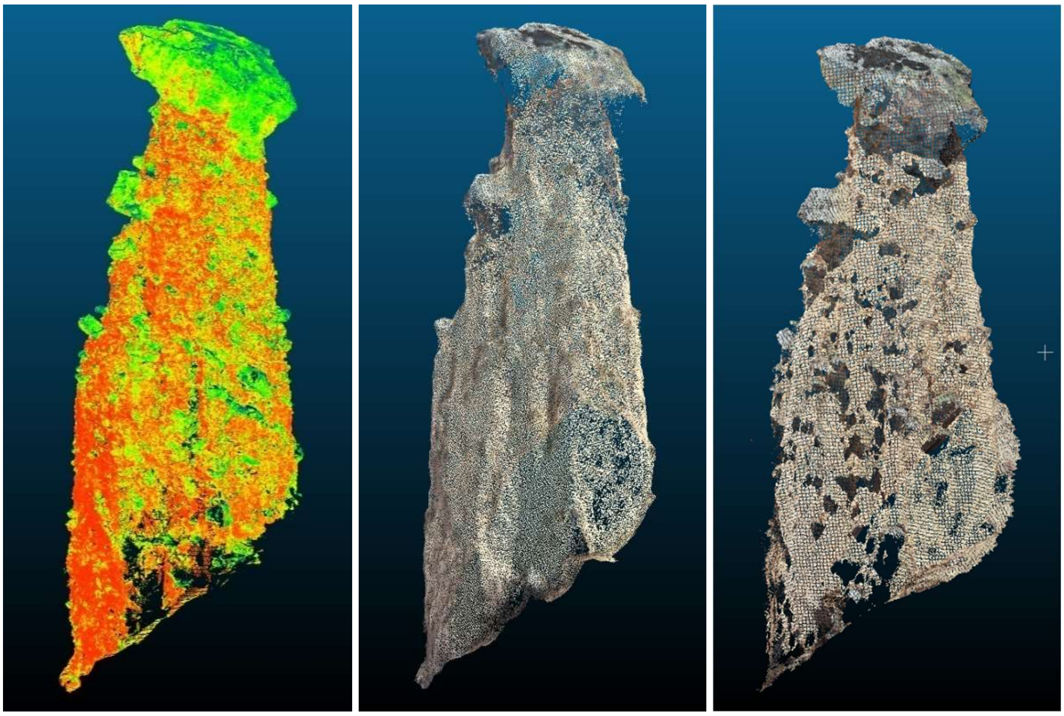

Figure 4. The point cloud of Barjaktar figure obtained by TLS method (left) and the point cloud of Barjaktar obtained by using UAV photogrammetry (middle 2018 and right 2024)

It can be seen that 3D model obtained in 2024 has more detail than the model generated in 2018, but model from 2024 also has lots of shadowed areas. This model was made from a much smaller distance but the UAV didn’t have a good perspective when fluing above the “Barjaktar” figure. For this particular case it would be better that some of the images were made with camera from the ground. Due to the lower level of detail generated in UAV 2018 mission, there was no sense in comparing these results with TLS point cloud. When comparing UAV 2024 mission with TLS point cloud it can be seen that there are still shadowed areas where comparation would not be appropriate. So erosion monitoring should be performed only between TLS missions from different epochs until better area coverage with UAV mission is performed. Model comparison of the “Barjaktar” figure generated from different TLS and UAV acquisition missions is presented (Table 2).

Table 2. Model comparison of earth pillar Barjaktar in TLS and UAV acquisition missions

Mission epoch and type	Number of points	Number of triangles	Spatial density [pnts per sqm]
2017 UAV	117 734	41 471	3 500
2018 UAV	207 820	94 737	6 600
2024 UAV	2 278 708	1 464 082	86 884
2017 TLS	668 907	1 322 612	16 981
2018 TLS	2 412 074	4 483 676	112 294

Point clouds of the “Barjaktar” created from data collected with UAV photogrammetry missions were generated by using Ultra High quality option when making dense point cloud in Agisoft.

Erosion monitoring was performed by using volume calculation function based on a grid in CloudCompare. Before that TLS models from 2017 and 2018 were finely registered cloud to cloud (Fig. 5) and distances between points from point clouds were calculated. It was calculated that the volume of eroded landslide material was 36 dm^3.

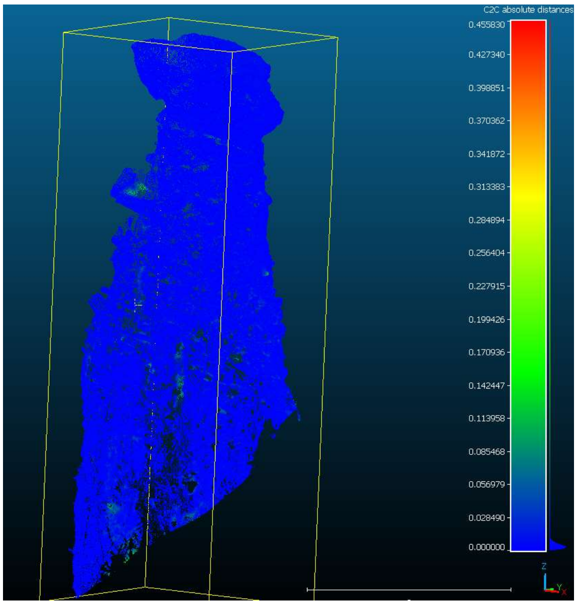

Figure 5. Comparison of TLS models from 2017 and 2018 time epoch by cloud to cloud distance

5. CONCLUSION

Modern laser scanners and UAV systems as measuring platforms are gaining more and more space in geodetic and other engineering activities. Fast, high-resolution data acquisition with optimal project costs brings TLS and UAV photogrammetry into the sphere of interest for the engineering and photogrammetry public.

UAV photogrammetry has the indisputable advantage of collecting data in inaccessible areas, especially when it is not possible to find a stable position to place the instrument, when compared to other methods, and now it is applied in many geodetic and engineering fields. Thus, UAV is extremely useful in recording and tracking objects, in engineering photogrammetry, but also in monitoring the behavior of the terrain in larger areas of interest. In this paper, the acquisition of data by the UAV system is shown, which enables very precise data for further analysis of the mutual comparison of the quality of the TLS and UAV systems.

As part of the research, it was noticed that the data obtained by the TLS method contained more detailed data compared to UAV photogrammetry, especially due to the higher spatial resolution. The application of the TLS method required the selection of stable places for placing the scanner stations, and the whole scanning process required more time, while with the UAV system the whole process takes much less time when performing automated flights. UAV photogrammetry had more advantages in the form of access to the shadowed objects in the area of interest. This was possible because UAV was much more mobile when compared with TLS and had a much bigger number of viewpoints.

By performing free flight UAV imaging with an optimal flight path it is possible to collect data for 3D model generation with much higher spatial resolution due to the shorter distance from earth pillars. In this way also shadowed areas will be avoided as much as possible. This was much better than the missions performed in the past with almost nadir images captured from a bigger distance above the earth pillars.

Rockfall occurrence is possible to detect with UAV photogrammetric missions especially when comparing models during longer period of time. With TLS method it is possible to quantify changes like erosion rate and ground subsidence. If UAV missions are planned in detail and with much better mission coverage it will maybe give even better results than TLS especially due to the limitation of this kind of scanning and producing shadowed areas. Another solution for overcoming these limitations would be laser scanning with high precicion LiDAR sensor mounted on an UAV but with a possibilty to control the angle of scanning sensor and get much better coverage of the area and higher level of detail.

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