Using UAV photogrammetry to document rock outcrops

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The purpose of this article is to present the usability of UAVs for the creation of large-scale photogrammetric documentation of geological rock outcrops, including their inaccessible parts. Currently manufactured low-cost UAV carriers are an interesting and progressive solution in terms of the processing cost for documentation of geological phenomena. Their main shortcomings are compact digital cameras used due their low weight with respect to the capacity of these UAVs. In our research, we aimed to verify the usability of digital photogrammetry with UAV for geological documentation of rock outcrop. This issue is addressed in several papers (Fritz et al., 2013; Niranjan et al., 2007) and produces interesting results. Our aim was to test a mass-produced, low-cost UAV model to create photogrammetric documentation of the surface quarry Lehôtka pod Brehmi. In this quarry, there is a large artificial rock outcrop, which was formed by mining activities. This outcrop is interesting in terms of the amount of information about the geological structure of the deposit, which can be observed in one place. A large part of the outcrop is inaccessible due to the total height of the outcrop, which is about 75 m. The entire outcrop has been photogrammetrically imaged using UAV. The integrated photo profile was created in the software environment Agisoft PhotoScan. For the purpose of visualization, a 3D model of the whole outcrop was also created. Obtained data will then serve as a basis for the model of the geological structure of deposits.

Key words: *UAV, photogrammetry, rock outcrops, geology, documentation.*

Introduction

A digital camera is standard equipment of every geologist when documenting natural phenomena. It enables detailed capture of a big amount of valuable information. Current progress in the use of unmanned aerial vehicles (UAV) gave the geologists an opportunity to document the normally inaccessible parts of geological objects (rock outcrop) or dangerous parts of the field (pitfalls, etc.). UAV with a digital camera enables to document geological outcrops, large areas and inaccessible objects and to obtain valuable missing data.

Digital photogrammetry is one of the methods used when documenting geological phenomena. It is used in geology, for example, when documenting:

- Rock outcrop
- Geological structures
- Surface quarries
- Underground mining works
- Caves, etc.

In this article, we will focus on the use of UAV photogrammetry for documentation of rock outcrops. Basic principles of photogrammetry are now successfully implemented in robust computer algorithms, which are able to process digital images automatically to 3D coordinates of the millions of generated points known as point clouds. The processing of digital images is done in specialised photogrammetric software. Because the source data are colour digital images, the 3D data can also carry RGB information about the each pixel. Therefore, we are able to produce photo-realistic 3D models, which can then be exported as 3D models to other professional software, for example CAD, GIS, etc. (Molčíková and Hurčíková, 2013). These models can also be exported to freeware 3D imaging formats (including Adobe Reader for 3D PDF).

3D models created on the basis of photogrammetric data provide a better understanding of spatial relationships between geological objects to geologists, allow to link various information to a model such as a geological map, geological cross-sections, 3D model of the territory, etc. (Pukanská et al., 2014; Palková and Zelizňaková, 2015).

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Study area

Perlite deposit Lehôtka pod Brehmi is situated near the village Lehôtka pod Brehmi in the district Žiar nad Hronom. It is situated in the range of area Štiavnické vrchy and Ždiarska kotlina. This surface quarry and its surroundings belong to central Slovak neovulkanits. In the mining area Lehôtka pod Brehmi, the perlite is currently mined by the company LB MINERALS, a.s.

Fig. 1. Area of interest - perlite deposit Lehôtka pod Brehmi.

Fig. 2. Rock outcrop under documentation.

Perlite is a rock subsumed to volcanic glass created by rapid cooling of the volcanic melt. It belongs to ecological materials with an excellent thermal insulation and also sound insulating characteristics. Raw perlite is expanded in a mineral processing plant near the quarry.

In terms of mining and the efficient use of raw materials from the quarry, it is important to understand the geological structure of the deposit. The deposit is opened as a surface quarry, and the extensive rocky outcrop is situated in its western part (Fig. 2). The geological structure of the outcrop is clearly visible there. This part of the deposit was selected as a test site to verify the applicability of the UAV photogrammetry for documentation of rock outcrops.

Methods, equipment and application

Photogrammetry

Photogrammetric methods have been used for 150 years, basically since the invention of photography. During that time, the photogrammetry experienced significant developments from analogue to today's digital methods. Significant development can be seen in recent years in the field of sensing devices. UAVs have become an advantageous alternative to conventional platforms. Progress has also been made in the processing of the images. Image processing is done via specialised software. Digital images captured from UAV are frequently processed using conventional methods or using the new and efficient method Structure from Motion, which operates under the same principles as stereoscopic photogrammetry, but the 3D structure can be generated from a series of overlapping images.

The quality of used digital camera and lens is very important for image processing. Optical errors can be corrected by camera calibration. Professional surveying photogrammetric cameras are usually calibrated from production. The elements of the camera calibration can be additionally performed in a laboratory using specialised software (e.g.,. AGISOFT Lens, PhotoModeler Scanner). Some software, for example AGISOFT PhotoScan, can perform the calibration automatically when processing images. Given the characteristics of unmanned carriers, the UAV photogrammetry often uses non-professional cameras. A simple digital compact cameras or a simple digital camera directly integrated into the UAV are often used. The most common method to determine elements of external orientation is the use of ground control points with known coordinates determined by geodetic methods in the field. Currently manufactured low-cost UAVs are equipped with GPS and IMU modules which can determine the position of the camera at the moment of exposition. That data is then stored with each image as its metadata. The results of the processing of the aerial images in specialised software are typically orthophoto map, point cloud or digital elevation model (DEM) (Hurčíková, 2011).

Unmanned Aerial Vehicle

Unmanned Aerial Vehicle (UAV) carriers for a wide variety of sensing devices are a technological advancement that has in recent years started to be used for mapping of surface structures (Colomina and Molina, 2014; Remondino et al., 2011; Neitzel and Klonowski, 2011). The trend in this area is to equip a UAV with navigation technologies - a global navigation satellite system (GNSS) and inertial measurement system, which are used for orientation in the environment. Based on this, UAVs are becoming almost independent from the ground control station, and they capture images at predetermined positions (Irschara et al., 2010). Such UAVs, equipped with a navigation technology, started to be used also in the field of geology as aerial photogrammetry equipment carriers in order to document the geological outcrops and other surface objects (Colomina and Molina, 2014; Polat and Uysal, 2015; Costantino and Angelini, 2015; Bemis, et al., 2014; Mesároš, 2015). Advanced UAV (Fig. 3) offers an easy handling with improved control software (Siebert, S. and Teizer, J. (2014). It contains the UAV carrier as well as a control centre on the ground (Mozas-Calvache, et al., 2012). Working with UAVs also includes flight planning, in addition to the actual flight with data acquisition (Shahbazi, et al., 2015). The last phase is an evaluation of images and creation of orthophotos and generation of the 3D terrain model.

As part of our research in the perlite quarry Lehôtka pod Brehmi, the UAV Phantom 2 Vision+ was used for rock outcrop documentation. UAV technical parameters are given in Table 1. The lens characteristics are causing a large distortion at the edges of the image – the so-called fisheye effect. However, such images can be corrected by appropriate software (e.g. Adobe Photoshop Lightroom).

Tab. 1. The selected technical parameters of UAV DJI Phantom Vision 2+.

Aircraft	
Weight (Battery & Propellers included):	1242g
Max Ascent / Descent Speed:	6 m/s / 2 m/s
Max Flight Speed:	15 m/s (Not Recommended)
Diagonal motor to motor distance:	350 mm
Camera	
Operating Environment Temperature:	0℃-40℃
Sensor size:	1/2.3" = 6.17 mm x 4.55 mm
Effective Pixels:	14 Megapixels
Resolution:	4384×3288
Focal length	5 mm
Recording FOV:	110° / 85°
Remote Control	
Communication Distance (open area):	CE Compliance: 400m; FCC Compliance: 800m

Fig. 2. UAV - Phantom 2 Vision+.
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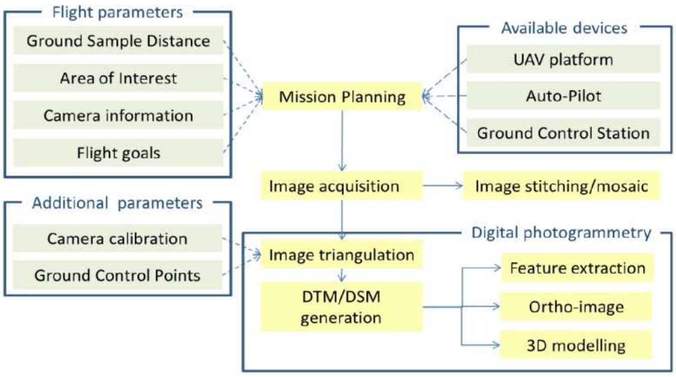

Fig. 4. Workflow for UAV data acquisition and processing (Nex and Remondino, 2013).

Data processing

The workflow for UAV mapping is similar to the workflow of man-based aerial mapping systems. The mapping workflow consists of the definition of the preparation phase, flight planning, autonomous flight, quality check of the data and data processing. The final data products are elevation models, orthoimages, 3D models (Eisenbeiss, 2011). The general workflow for UAV data acquisition and processing is in Figure 4.

The test area – the western part of the quarry Lehôtka pod Brehmi was photogrammetrically surveyed using UAV DJI Phantom 2 Vision+ with a 14 Megapixels FC200 camera (camera parameters - Tab. 1). The flight was carried out in 5 stripes at the height of 35 m above the average height of the terrain (ground resolution of 0.01m/pixel at 35 m flying height). 58 images were captured. 18 Ground Control Points (GCPs) with coordinates acquired by GNSS RTK method were used for location and registration of the images (Fig. 5). The coordinate system S-JTSK (Datum of Uniform Trigonometric Cadastral Network) and vertical coordinate system Bpv (Baltic Vertical Datum - After Adjustment) were used. The Structure from Motion approach of image processing has been implemented using the AGISOFT PhotoScan software environment. For the selected part of the quarry with a large rock outcrop, the digital terrain model and the photo plan of the quarry walls were generated. These outputs, especially the photo plan, were subsequently used as a graphical background for identification of geological structures, their documentation and insertion into the geological map.

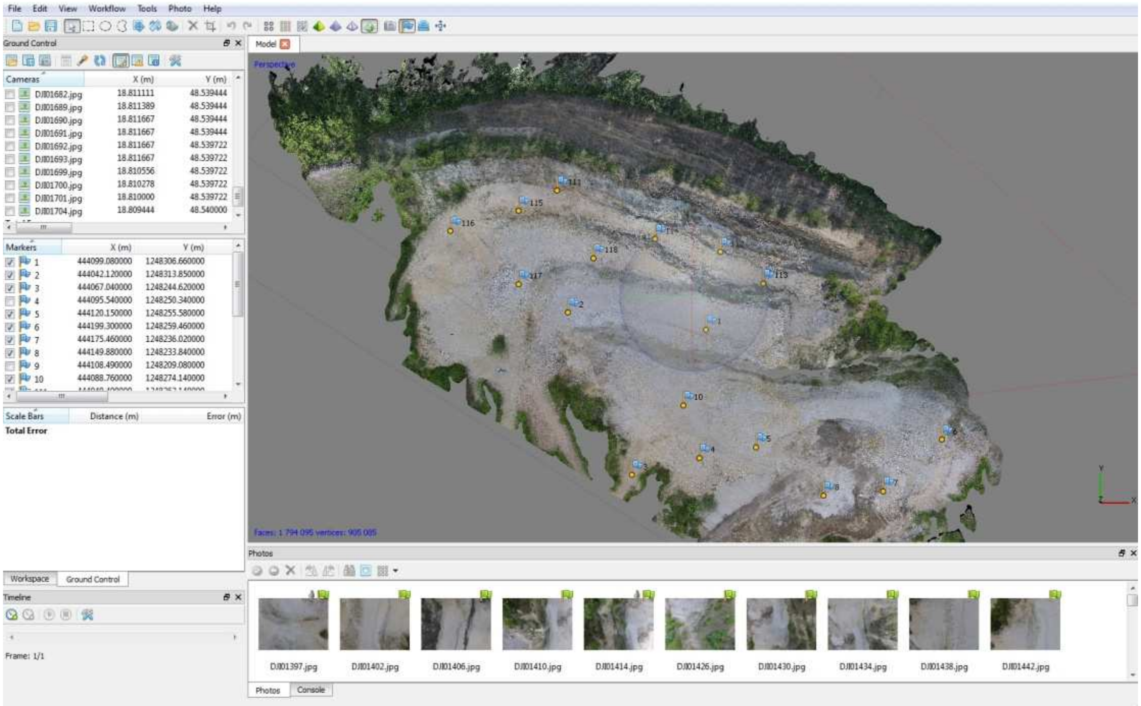

Fig. 5. Image processing in Agisoft PhotoScan software – result of the processing as a textured point cloud.

Results and Discussions

The result of the processing is a point cloud representing the 3D model of the surface (Fig. 4). Subsequently, the point cloud was exported into an ASCII text file. The coordinates of the points and information about the real colour of the pixel in the RGB colour model were also exported. The colour of points was derived from the aerial photographs. Subsequently, the point cloud was processed in the CAD software.

In addition to the point cloud, the photo plan of the rock wall (Fig. 6) was generated. It was used as a graphical background for identification of geological structures, visible in the images. The geological boundaries were plotted into this photo plan (Fig. 6) and the results were compared with the measurements and in the field.

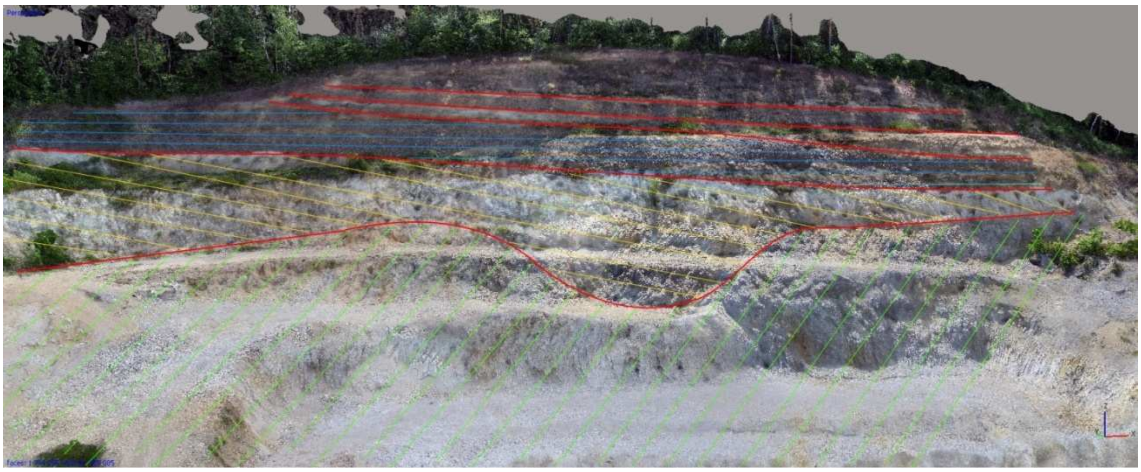

Fig. 6. Geological structure interpreted on the basis of the photo plan.

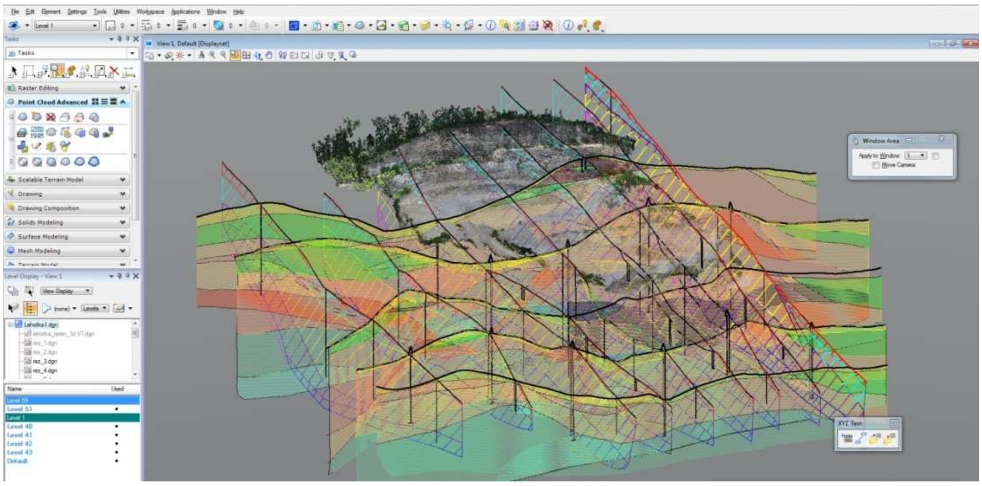

Fig. 7. Comparison of point cloud inserted into the CAD software and historical model of the geological structure with current state obtained photogrammetrically.

One of the goals of this paper was to show the possibility of using photogrammetric data outputs when creating a model of a geological structure. One of the outputs of processing in Agisoft PhotoScan software was a point cloud, which has been imported into the CAD software MicroStation. A simple 3D model of the outcrop was created using this CAD software. Historical data - 14 geological sections and the geological map of the surface were used. Through this model, the point cloud was subsequently inserted (Fig. 7). By joining these two models, it is possible to perform the analysis of the accuracy and quality of the historical model. Due to the fact that each of the displayed points also carries information about the real texture (RGB model), we can view this dense point cloud as a clear continuous textured surface (Fig. 7). The point cloud presents a cross-section of the geological structure of the mineral deposit and allows to correlate historical assumptions about the geological structure with the state documented in the field at present (Fig. 8). The actual real geological situation can be inserted into the historical model using the drawing functions of the CAD software.

The correlation between the historical spatial model and the model created by the data obtained photogrammetrically is presented in the Fig. 8. Geological boundaries identified in the photogrammetric model does not fully correspond to historical ones. The average difference between the two models is up to 1m. These differences are consequences mainly to the precision of the analogue geological maps and sections, the scale of historical maps and errors in vectorization process. In general, these values can be acceptable. A significant difference between both models up to 4 m is mainly in the central part of the quarry walls (Fig. 8, area B), where is the observable geological structure that may not have been documented by previous geological surveys so that is not contained in the historical model. The accuracy of the historical model is directly dependent on the amount of input data – quantity of boreholes on which the model was created. Subsequent interpretation of these data is depending primary on the experience of geologists. Geologists interpret information from boreholes and create a model of the geological structure, which should be realistic enough. In our case, a significant difference was identified between the two models with the size up to 4 m indicated in Figure 8 as area B.

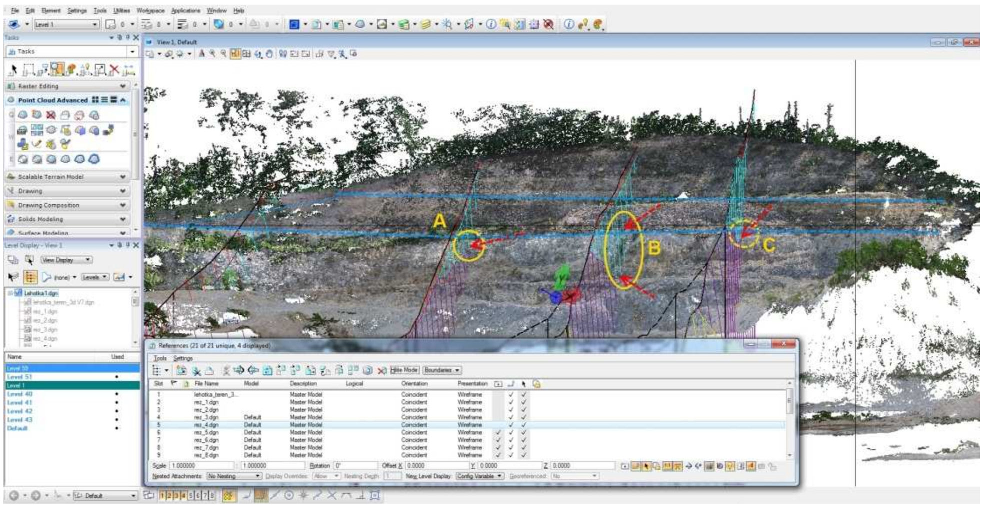

Fig. 8. Correlation of the models of the geological structure of the mineral deposit.

Another possibility of use of the results of photogrammetric data processing is the creation of a digital surface model. This can also be imported into a CAD system and along with a textured point cloud, we can obtain a good basis for the indirect acquisition of some geological measurements (e.g. direction and the angle of inclination). A digital surface model with a high resolution allows producing a relatively accurate measurement of structural parameters. Its advantage is the possibility to perform measurements on a structure which would be otherwise inaccessible for geologists in the field.

Conclusion

Photogrammetry in combination with UAVs and application of these technologies in geology for the documentation of inaccessible or large-scale natural or artificial geological outcrops appears to be a progressive solution in terms of accuracy and efficiency. This paper presents the use of low-cost UAV photogrammetry for the creation of geological documentation on the example of the inaccessible rock outcrop in the quarry Lehôtka pod Brehmi. The outputs of photogrammetric data processing using software Agisoft PhotoScan are the photo plan of the rocky outcrop, textured point cloud and the digital terrain model. These outputs were used by geologists as a basis for the verification of historical assumptions of the geological structure of the mineral deposit. The geological structures were identified in the photo plan. They were subsequently correlated as an imported point cloud with the geological model obtained from historical data in the CAD system. This process allows the geologist to evaluate and compare these two models in a relatively simple way and based on new results reinterpret historical views on the geological structure of the deposit.

The results clearly show the advantages of using low-cost UAVs and cameras when collecting geological data. Generally, we can consider the used method (aerial photogrammetry in connection with a low-cost UAV) as a suitable tool for the spatial data collection when documenting natural and artificial rock outcrops. In terms of quality and detail of the created model, we can say that such models achieve the required accuracy thanks to well-developed mathematical principles of digital photogrammetry and used software.

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