DOCUMENTATION OF LANDSLIDES AND INACCESSIBLE PARTS OF A MINE USING AN UNMANNED UAV SYSTEM AND METHODS OF DIGITAL TERRESTRIAL PHOTOGRAMMETRY.

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Abstract

Quite a big boom has recently been experienced in the technology of unmanned aerial vehicles (UAV). In conjunction with dense matching system, it gives one a powerful tool for the creation of digital terrain models and orthophotomaps. This system was used for the documentation of landslides and inaccessible parts of the Nástup Tušimice mine in the North Bohemian Brown Coal Basin (Czech Republic). The images were taken by the GATEWING X100 unmanned system that automatically executed photo flights an area of interest. For detailed documentation of selected parts of the mine, we used the method of digital terrestrial photogrammetry. The main objective was to find a suitable measurement technology for operational targeting of landslides and inaccessible parts of the mine, in order to prepare the basics for remediation work.

Keywords: Unmanned Aerial Vehicle (UAV), Dense matching system, 3D model, Point cloud

1 INTRODUCTION

The Nástup Tušimice mine is located in the North Bohemian Brown Coal Basin. The company Severočeské doly, under which the mine in question falls, produces around 23 million tonnes of brown coal and is the largest producer in the Czech Republic. The Nástup Tušimice mine primarily produces thermal coal amounting to about 13.5 million tons, while the main customers are the thermal power plants of the ČEZ company. At the request of Severočeské doly, a suitable methodology was to be designated for operational focus on landslide areas and inaccessible parts of the mine. 3D laser scanning technology was to be taken into consideration, which we had already applied in the area of scanning of bucket wheel excavators for mining management systems in real time and also terrestrial and aerial photogrammetry (Vrublová, D., et al. 2012; Sládková, D. et al. 2011). With regard to cost, time demands and logistical availability, methods for digital terrestrial photogrammetry and UAV systems were selected and tested.

2 GATEWING X100 UNMANNED AERIAL PHOTOGRAPHY SYSTEM

This is a unique system for unmanned aerial imagery acquisition and exploration at a height of a few hundred meters. It is at a lower cost and is with fewer requirements for preparation, take-off and landing sites, as well as unfavourable weather conditions (wind, rain and cloud cover) than with traditional aerial photography. The system is developed by the company GateWing, a member of Trimble. The aircraft weight is less than 2 kg and the wingspan is only 100 cm. It is a single-engine propellor model with an electric drive and control unit enabling navigation using GNSS (Table 1). During the flight, data is recorded on the position of designated centers of each image in the system WGS84. The aircraft is also fitted with an integrated inertia system for measuring tilt and Prandtl pitot tube for measuring the speed of the model. The system can be applied to topographic mapping , mining (calculation of volumes, mapping hazardous and inaccessible areas), building and transport engineering (roads, bridges, intersections, channels, floodplains), agriculture and forestry, aerial exploration (geology, archaeology), documentation of emergencies (natural disasters , accidents) (Jiránková, E. 2012; Křivda, V. 2013; Dandoš, R. et al. 2013).

Before photo flight, there were carried out pre-flight checks, visual and technical checking of important areas, definition of the imaging area in GoogleEarth and setting up of the projected imaging (pre-defined area coverage). The plane is made of polypropylene and is fully automatic from takeoff to landing. An area of several square kilometers can be photographed on a single charge. The air is catapulted with a special platform with an angle of attack of 15° (Figure 1). Pictures are taken in succession with sufficient overlap. Positional accuracy of CP (XY plane) is 5 cm and height accuracy (Z axis) 10 cm at a height of 150 m. Using Agisoft PhotoScan we created a precise spatial terrain model and orthophoto mosaic.

Fig 1. GATEWING X100 – take-off platform, shots of Nástup Tusimice mine

Tab 1. Basic system parameters GATEWING X100 (Website Trimble)

DRIVE
Electric brushless motor 250 W Pusher propeller Lithium - polymer battery 11.1 V, 8000 mAh
EQUIPMENT
Calibrated 10 megapixel digital camera Autopilot, automatic take-off and landing
PERFORMANCE
Flying speed 75 km / h Max duration 45 min Flight altitude 100-750 m
OPERATIONAL INFORMATION
Take-off prep. time 15 minutes Take-off method- catapult Communication frequency 2.4 GHz Weather - windspeed up to 65 km / h & light rain

Photographing took place on 23.5. 2013 in Nastup Tusimice mine, time of photographing 11:00 to 12:00 am, overcast, temperature 13 ° C. The images were taken using a RICOH GR Digital IV digital camera with a resolution of 10 megapixels and 28 mm wide-angle lens, shutter aperture f/4, length of exposure 1/1000 sec., ISO 400, focal length 6 mm. The lens features a high aperture and low chromatic aberration and optical distortion. Photographing was divided into two separate projects. The project covers an area, which was, on the same day focussed on terrestrial photogrammetry. In the first stage, 410 images were acquired at a resolution of 3648 x 2736 in 10 strips, covering an area of 0.53 km^2. In the second stage, at an identical resolution, 50 frames were acquired in six strips, covering an area of 0.16 km^2 (Figure 2). Statistics of the model are shown in table 2.

Tab 2. Statistics of GATEWING X100 unmanned aerial photography system

GATEWING X100	Project 1	Project 2
Number of images	410	50
Average altitude	194 m	167 m
Number of strips	10	6
Resolution	0,06 m/pix	0,05 m/pix
Covered area	0,53 km^2	0,16 km^2
Image parameters	3648 x 2736	3648 x 2736
Focal length	6 mm	6 mm
Error	0,5 pix	0,7 pix

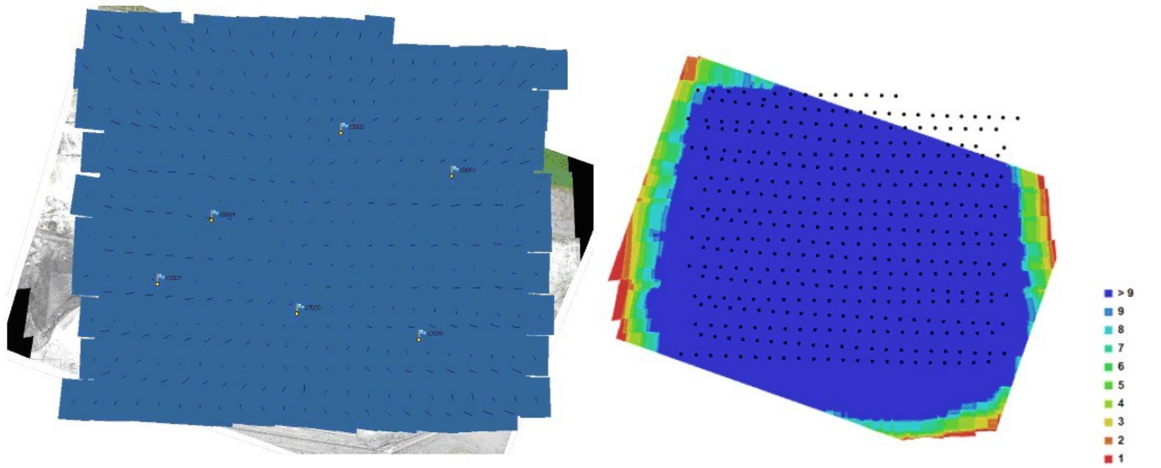

Fig 2. Agisoft PhotoScan - Project 1 with ten strips, centre location designation

Evaluation was carried out in a similar way to terrestrial imaging in the Agisoft PhotoScan program. Internal orientation program data elements are automatically extracted from the EXIF metadata. When creating models, the Height field option is set for the interpretation of aerial photographs. The point cloud did not require cleanup of unwanted objects and background. A cloud was created that closely resembled a terrain relief without unwanted noise (Figure 3). The 3D model from project 1 was attached to the coordinates using eight artificially indicated control points, for the model from project 2, six control points were used. The coordinates of the control points are determined by the Trimble R8 GNSS RTK apparatus and transformed into the systems of S-JTSK and Bpv. We used the artificially existing control points (white cross), which are indicated in all localities of the mine and used for conventional aerial photography.

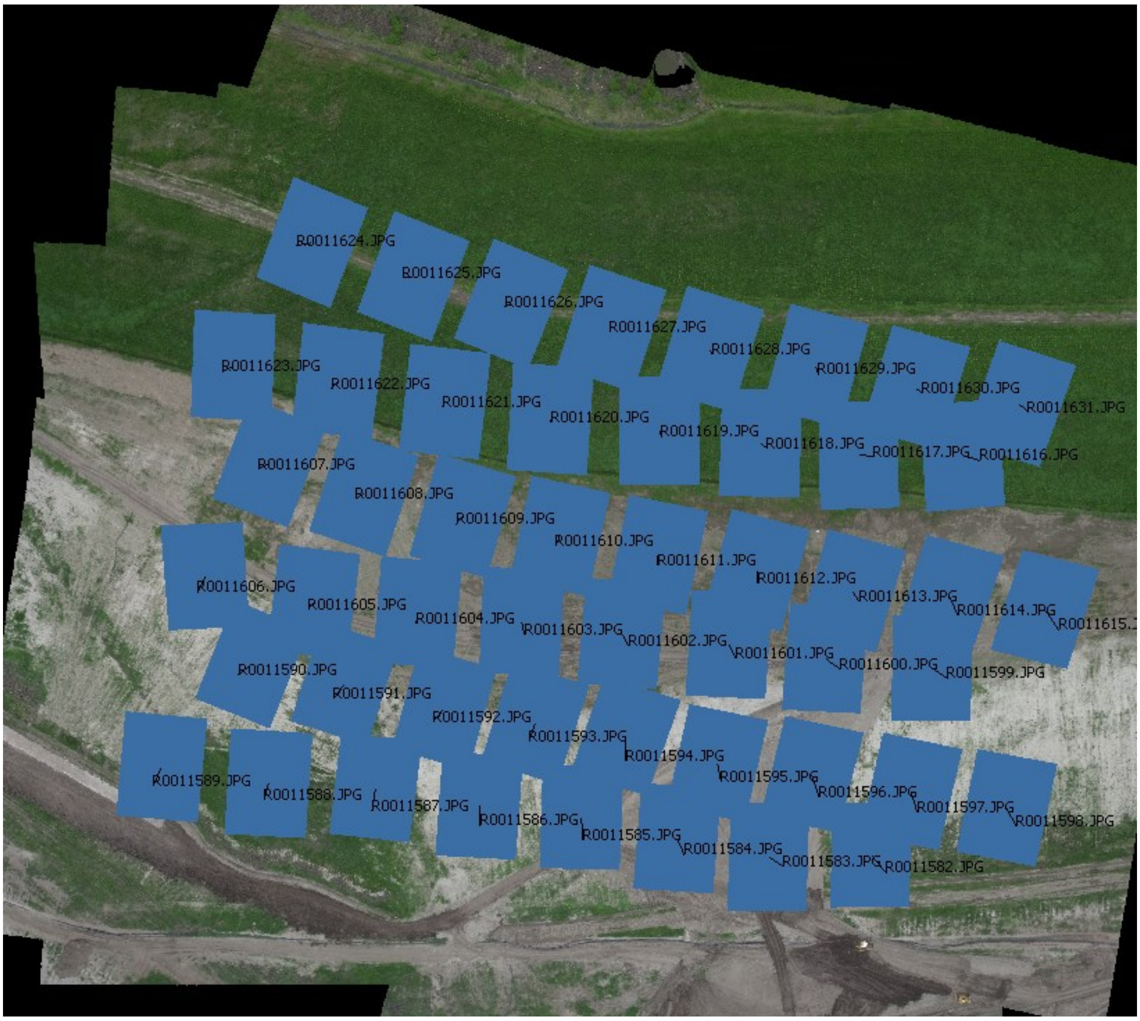

Fig 3. Agisoft PhotoScan - Project 2 with six strips

The minimum deviation with transformation to control points and equalization of the bundle of rays in Project 1 came out at:

- Mean error in the X-axis 0.009 m (maximum residue 0.011 m),
- Mean error in the Y -axis 0.002 m (maximum residue 0.003 m),
- Mean error in the Z-axis 0.010 m (maximum residue 0.004 m),
- Total Error (pix) 0,3.

In the case of Project 2:

- Mean error in the X-axis 0.025 m (maximum residue 0.046 m),
- Mean error in the Y -axis 0.025 m (maximum residue 0.041 m),
- Mean error in the Z-axis 0.048 m (maximum residue 0.068 m),
- Total Error (pix) 0.3.

The 3D model of Project 1 was subsequently exported to orthophotos (coordinate system S- JTSK, dimensions 16827 x 14225 pixels, 96 dpi resolution , image format * . tiff) and to the format wavefront *.obj. The 3D model of Project 2 was exported to orthophotos in sizes 9072 x 8176 pixels.

Furthermore, we focused on the part that we had evaluated in detail by terrestrial photogrammetry (Figure 4). From the aerial images, I chose 33 images. Imaging parameters are the same as for Projects 1 and 2, with the exception of the size of the covered area (0.17 km^2), the number of strips.

When creating a 3D model we chose "Height field" for data from aerial photography and geometry "smooth" to creating a smooth model without holes. The quality of the model creation was set to "High" with the maximum number of created surfaces set at 2 000 000. To The cloud, we connected a real texture with a height and width of 5096 pixels in the general processing and the orthophoto modes.

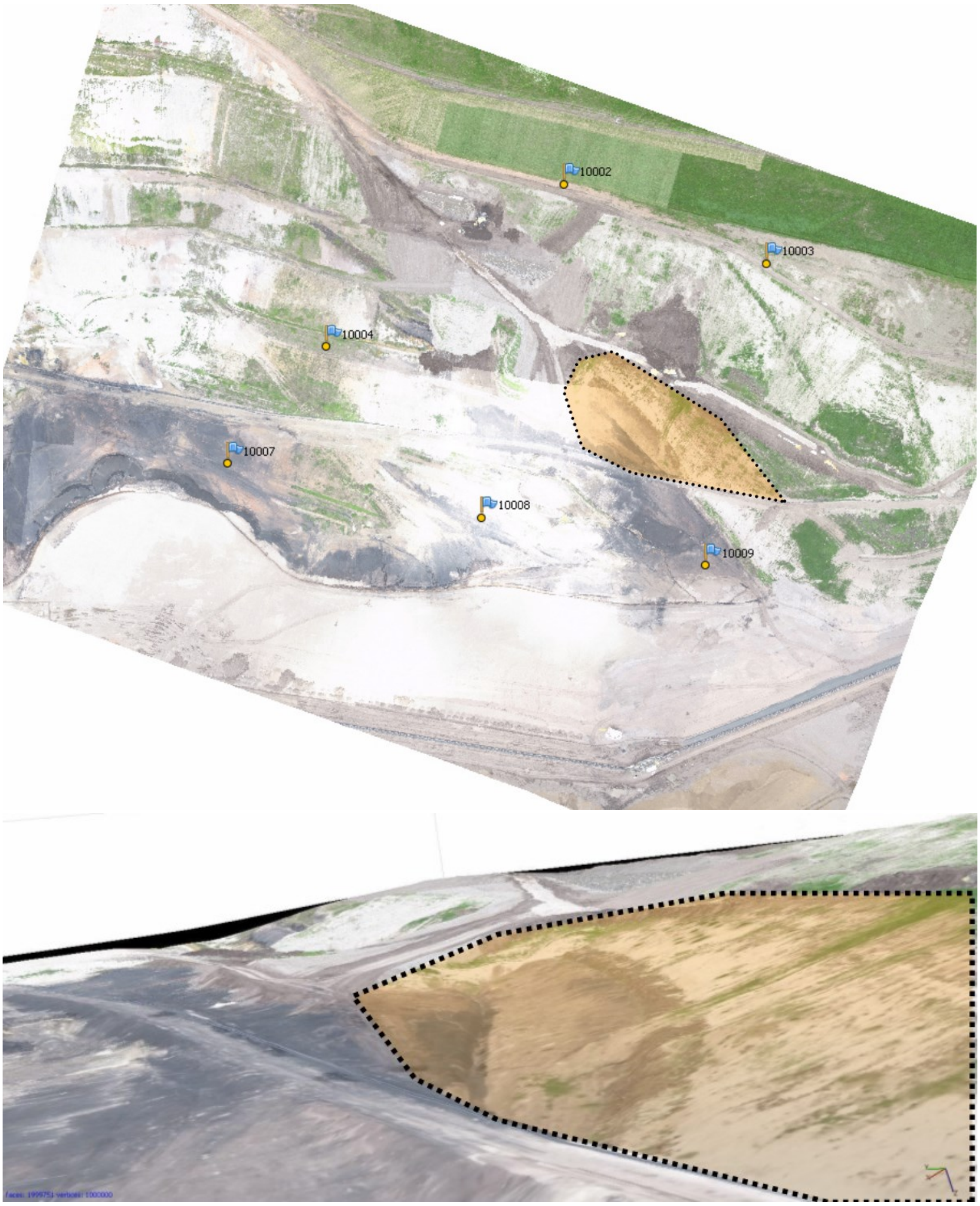

Fig 4. Evaluation of the GATEWING system and terrestrial photogrammetry

Using the freeware version of CloudCompare (Open Source Project), we can evaluate the remoteness of the model in comparison with a reference model. In this program, we compared the data taken from ground and aerial photography. From Figure 5, it is apparent that the geometry of the two models is similar. Important edges and inequality are interconnected. In the central part of the 3D model of terrestrial photogrammetry, differences range from about ca. 10 cm to 20 cm. Towards the edges, differences are larger than 20 cm. The comparison took place at fractured and clearly visible edges.

The aerial photography model was not necessary to further optimize and clean up afterwards. The 3D model faithfully captures the topography, but is not as detailed as with terrestrial photography. Of course it depends on the flight altitude and the quality of the image recording. Using aerial photography though, broad and inaccessible areas of the mine can be mapped. The accuracy of both models is sufficient for the intended purpose, ie. to operatively document the current situation of the mine and landslides and inaccessible areas.

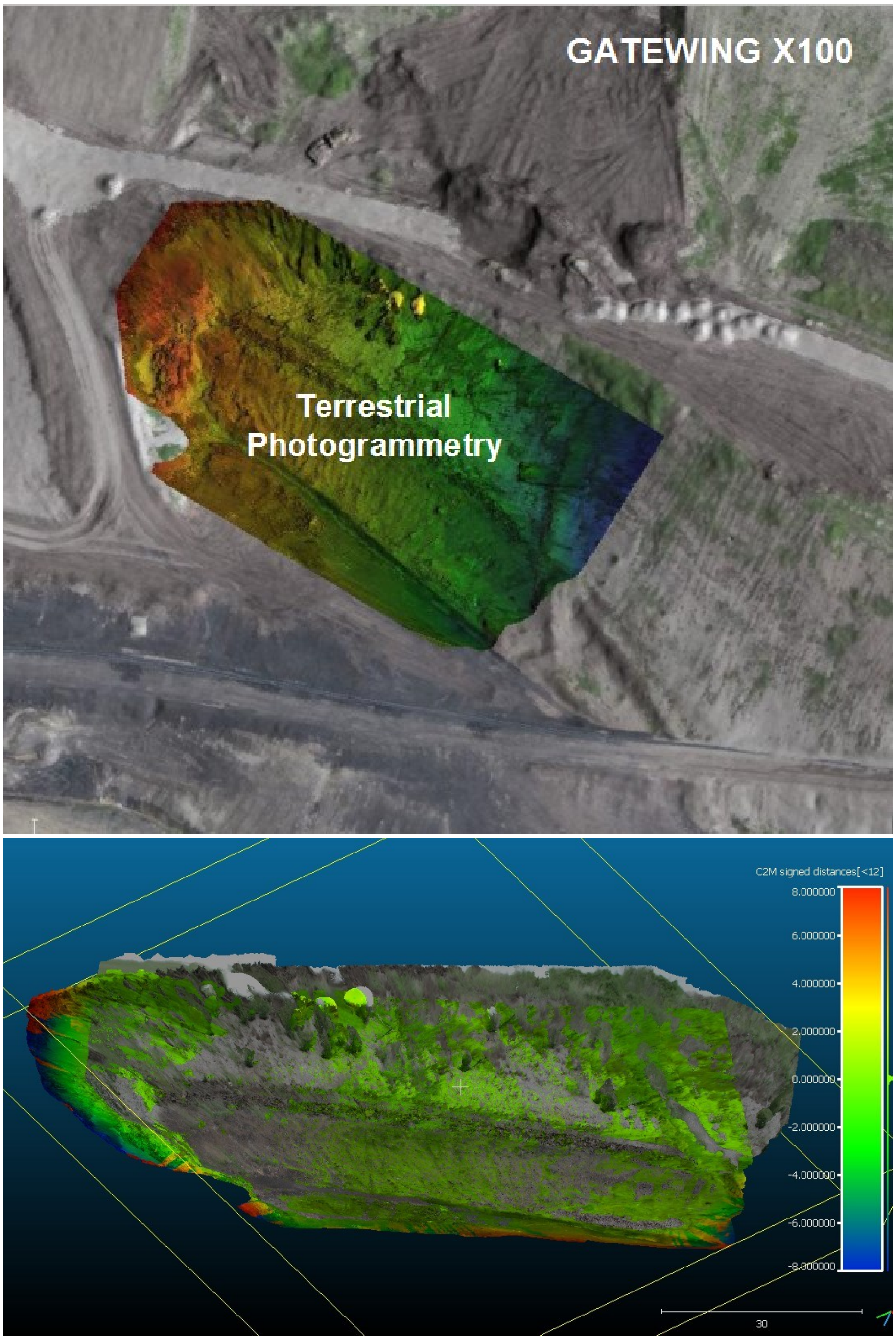

Fig 5. Comparing geometry of both models in CloudCompare. Variations in the legend [cm]

3 TERRESTRIAL IMAGING

Photographing took place on 23.5.2013 in Nástup Tusimice mine, time of photographing 12:00-13:00 pm, overcast, temperature 13 ° C. The fixed focal length was 18 mm (equivalent to film format 28.8 mm). We used a digital SLR Canon EOS 7D with Canon lens EF-S 18-135 mm f3, 5-5.6 IS and resolution of 19 megapixels. We created the 3D model of the mine landslide area, using Agisoft PhotoScan Pro version 0.9.0.1542 (64 bit) from AgiSoft LLC and PhotoModeler Scanner 6.3.3.794 from Eos Systems Inc. The program includes Agisoft PhotoScan which,like the below mentioned program PhotoModeler Scanner belongs among dense matching system. The program will automatically search for identical points of the image, ie. correspondence with various images. Identical points are assigned to each program, and this data computes the position of photogrammetric stations. A cloud of points is created which can be coloured according to real textures. In the next step we created a geometric object represented by a triangular mesh, on which then, the texture with a defined resolution is connected. Calculations are demanding on hardware. With a powerful computer, a better model and textures in higher resolution can be generated.

The terrain was indicated by 8 control points (coded targets of Photomodeler , 8-bit variant , ie. 25 unique targets) for connecting the model to the scale and coordinates. Control points were targeted by GNSS RTK Trimble R8 apparatus including control points for the GATEWING aerial photography system. Coded Photomodeler targets were also used to evaluate the 3D model in PhotoScan.

On the ground,the following were acquired:

- 26 convergent images,
- 25 parallel images,
- 9 pairs of images for creating an anaglyph with the base of 65, or 120 mm plate MANFROTTO 454 MICRO 120 mm.

3.1 Evaluation of the program Agisoft PhotoScan

The program works with convergent or parallel images. Orientation of images is done automatically based on the correlation of identical items and their surroundings. At this stage, the program PhotoScan specifies the camera position for each frame and creates a cloud of points. The orientation quality can be set at three levels "High - Medium - Low". Higher accuracy is achieved by setting a more accurate estimate of the position of the camera in space. For the given task, "Medium" was selected as absolutely sufficient. The level of "High" unreasonably prolonged calculations and placed increased demands on the hardware. After alignment, unwanted objects and background (Clouds, moving objects, distorted objects, etc.), were removed. Despite the removal of unwanted objects in the process of image rotation, it was necessary to manually clean up the cloud of points. The process of creating a 3D model depends on the number and quality of images. The model was further optimized and the number of surfaces was reduced, ie. the model was decimated . Without this change, the time for making textures and exporting to orthophoto disproportionately increases. The decimation level is chosen so as to avoid degradation of the entire model (Fraštia, M. 2012; Ličev, L. et al. 2013). The statistics of the 3D models from convergent and parallel imaging are presented in Table 3.

During the scan, the following rules were observe (website agisoft):

- Use of a digital camera with 5 Mpix and more,
- Acquire images with sufficient overlap from different perspectives (three or more),
- Collect convergent and parallel images,
- Use of a wide angle lens rather than a telephoto lens,
- Imaging of a sufficiently structured and textured surface for easy retrieval of identical points,
- Avoiding glossy and transparent surfaces, moving objects in the foreground,
- Images acquiring in diffuse sunlight,
- No editing of images using a graphical editor before evaluating, and no cropping or use of geometric transformation.

Tab 3. Agisoft PhotoScan , 3D models statistics

Imaging system	Number of images	Number of points	Number of areas
Convergent	26	16 111	2 235 577
Parallel	25	44 246	7 189 103

With convergent imaging unlike parallel imaging, we covered a larger area and complicated places such as ditches and bumps.

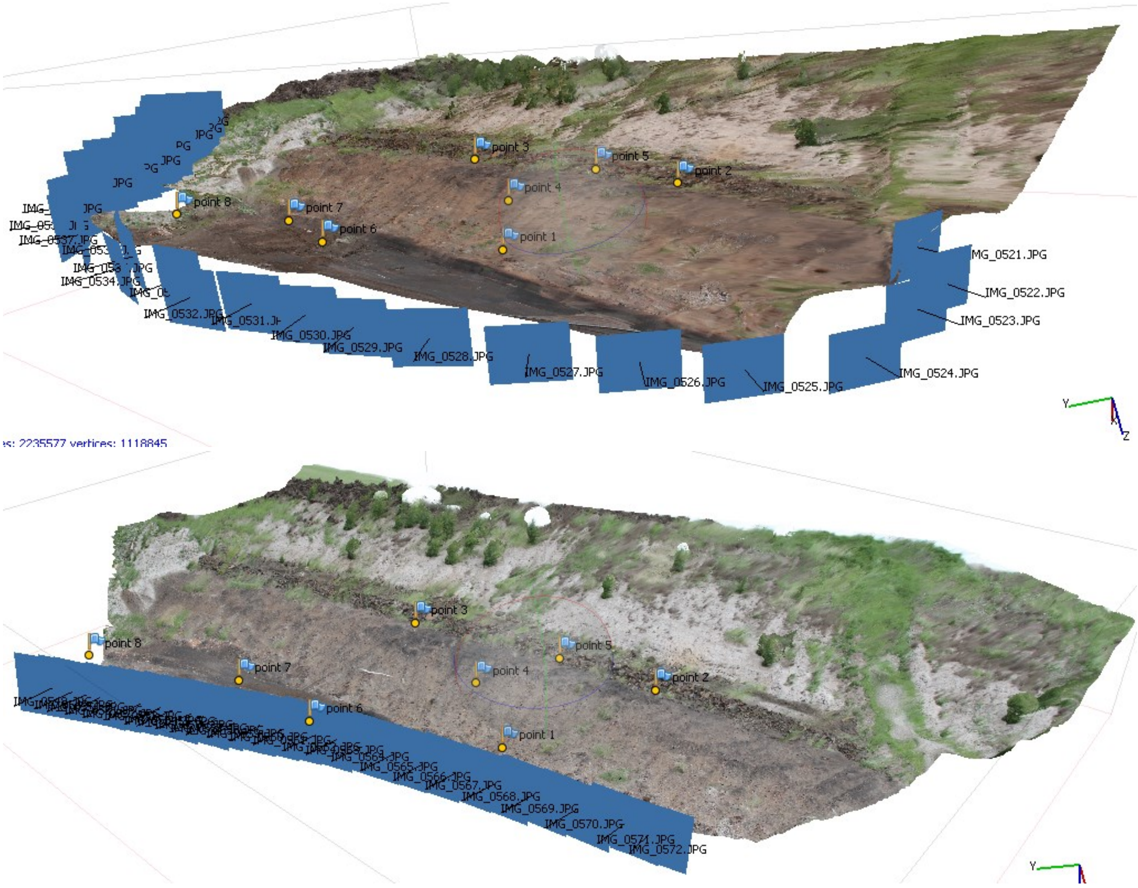

Fig 6. Convergent and parallel imaging - a model with connected texture

There followed the connection of real textures (Figure 6). If you only want to export to orthophoto, this step could be skipped. But in the case of real textures connection, we can visually check the measured results and accurately define the position of control points. Texture resolution was set to 4096 pixels in the general processing mode. After selecting appropriate control points with minimal residual deviation, transformation of the 3D model into an S- JTSK coordinate system was performed. We generated a model even in an area farther away from the centre of control points, this being only for the testing program. In this section there is a relatively large distortion of textures and noise. For the orthophoto creation, the Topol xT 9.5 DMT program was used. Topol xT is a general geographic information system for management and analysis of raster and vector data. The DEM option (digital elevation model) is the highest version of Topol xT and features the function to transform parts for correction of errors in elevation in raster and vector data. We optimized the Model in Geomagic Studio. Geomagic Studio is a complete set of tools for transformation and editing of spatial data. It is a powerful software tool for point clouds amendment and their editing (cleaning, filtering, analysis, repair, etc.). Geomagic Studio has a number of advanced and automatic features that improve the final appearance of the 3D model. After importing the 3D models, we selected the Mesh Doctor function for automatic optimization (very rugged sections, holes, crossings, etc.). Subsequently, we used the Denoise PointCloud option to suppress the noise signal. On the digital terrain model, we created several sections with 30 m intervals. The cut direction was defined in the plan by moving the mouse across the model. The resulting curves are saved as *. IGS files and imported into MicroStation or AutoCAD.

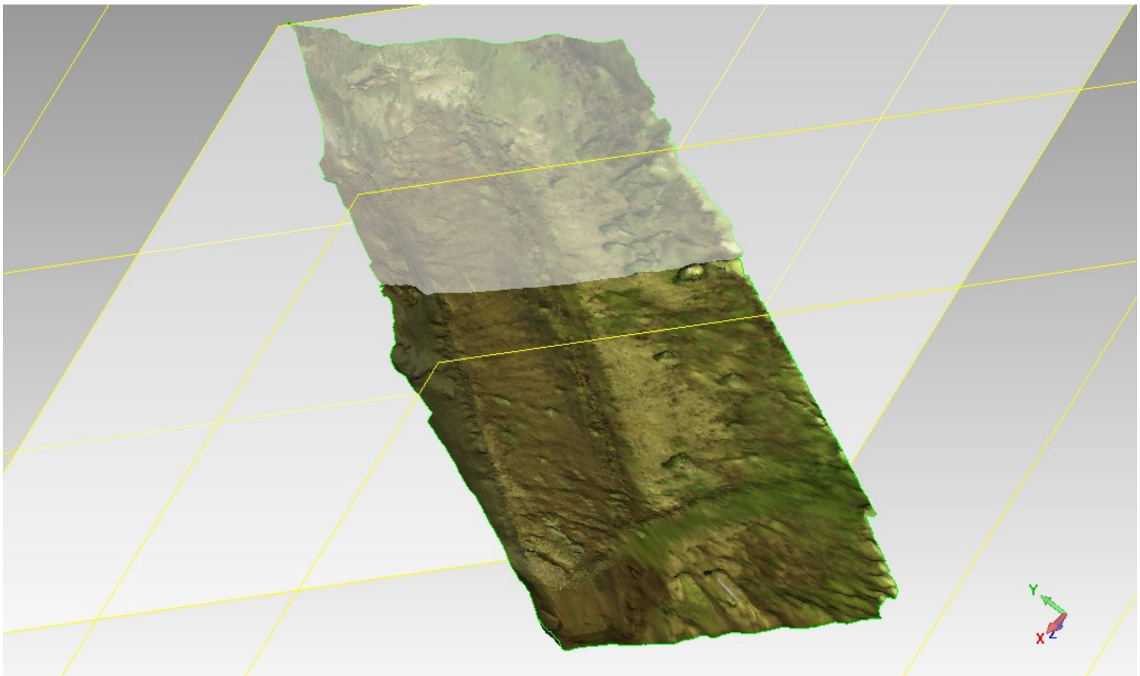

Fig 7. Making cuts in Geomagic Studio. ISO view of a 3D model.

We compared the 3D terrain model of parallel imaging in CloudCompare with the reference model, arising from convergent imaging. The central part of the model, which is the subject of evaluation, exhibits minimal fluctuation. The boundary of the model is covered with dense vegetation. Alternatively, it is an area that is not covered by the different imaging systems.

Geometry of models created on the basis of convergent and parallel imaging are almost identical and shows anomalies in the range of about ± 5 cm.

3.2 Evaluation in the PhotoModeler Scanner program

In this case, the photogrammetric system was developed by the Canadian company EOS Systems Inc. The program uses the method of convergent and parallel imaging for creating photorealistic 3D models. This Scanner option provides extra tools for creating point clouds (DSM surfaces - Dense Surface Modeling) similar to laser scanning. Parallel imaging is used for documentation of complex surfaces (slopes, bedrock, quarries, stone walls, etc.). For these areas, it is difficult to find identical points because referencing is not accurate. The measurement result is a dense set of points, as in laser scanning. The surface of the focused surface must be sufficiently structured and textured. Glossy, transparent and dull surfaces (water surface, polished surfaces, etc.), areas with a repeat pattern, or very segmented areas with a lot of edge discontinuity are not suitable. It is preferable to use a wide angle as oppose to a telephoto lens (Kapica, R. et al.). We arranged parallel images (parallel to the axis of the frame) and overlapping by at least 60 %. For creating vector drawings and thematic maps, we also used convergent images. Digital camera we calibrated on the spatial test field, which is indicated in the survey overseer, the Institute of Geodesy and Mine Surveying. There are 24 circular targets focused on surveying bases in the local coordinate system (Kapica, R. et al. 2011; Mikoláš, M. et al. 2014).

The PhotoScan program automatically extracts the necessary information from the EXIF metadata. This will significantly shorten the preparatory phase before commencing scanning in the field. It is not necessary to scan the test field. The parameters listed in the EXIF match the camera settings in the field. Despite this fact, the company Agisoft offers camera calibration using a checkerboard test field in black and white. The camera is calibrated in Agisoft Lens, which can be downloaded free of charge from the company website. The test field was displayed on a 102 cm UE40F6670 Samsung TV. Agisoft Lens supports conversion and import of calibration data from other software that use a different calibration parameter structure (PhotoModeler, CalCam , etc.). In practical trials, there were two to three percent variance values observed. Calibration results in Agisoft Lens approach the results seen in PhotoModeler Scanner and are sufficient for the required accuracy of the 3D models.

To evaluate the point cloud in this program we used parallel images. The point field is calculated from twin frames, and one can choose to run multiple combinations of frame pairs. There is some noise, the most being in low- structured and textured surfaces. I always used a set of three consecutive frames, with the middle image having a defined the area for creating point clouds. For the density of the point field, we chose a value of 5x5 cm (Figure 8).

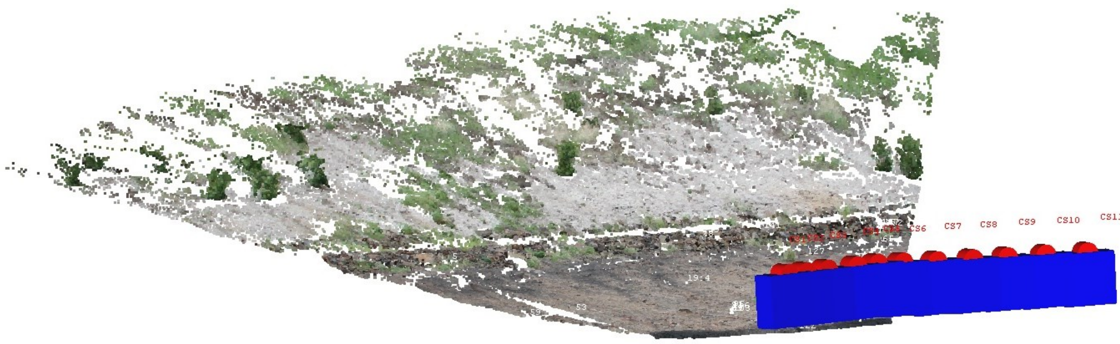

Fig 8. PhotoModeler Scanner - point cloud

We also used manual referencing of convergent images. Within the convergent imaging, 156 identical points on 25 frames were manually referenced. Identical points form the basis for the creation of a vector field model. Hand- referencing is quite time consuming, it being difficult to look for identical points on a surface. I referenced the edges of stabilizing walls and ditches, bumps and the sharp edges of stones. The outcome of measurement was functional maps of landslides and inaccessible parts of the mine (Figure 9).

4 CONCLUSION

Evaluation of landslide and inaccessible areas of a quarry using an unmanned system appears to be a quick and effective method. This is coupled with fewer costs and demands for preparation, sites for take-off and landing and worstening weather conditions in comparison with conventional aerial photography. If we use an dense matching system for the evaluation, we get a fairly accurate digital terrain model in the form of point clouds and an ortophotomosaic. The generated 3D model faithfully conveyed the terrain's relief without unwanted noise. The quality of the model depends on a number of factors, from the height of the flight to the video recording quality. The terrestrial imaging model was indeed sophisticated, but occupied a very small part, only 0.006 square kilometres of the total area evaluated, being 0.7 square kilometres covered with the unmanned system.

When using lower quality image orientation and model generation, the correlation system have a tendency to round off the edges. It is always necessary to make a compromise with regard to the hardware used and the time of calculation so that the model has a precision corresponding to the project assignment. A limiting factor in the use of correlation systems is that the surface of the focused object must be sufficiently structured and textured. Glossy, transparent and dull surfaces (water surfaces, polished surfaces, etc.), areas with a repeat pattern, or a segmented area with a lot of edge discontinuity are not suitable. We also compared the models resulting from ground and aerial photography. Individual field edges and inequality are interconnected. Terrestrial photogrammetry can be used for detailed documentation of smaller areas. In the ground surveys model, inequalities and the terrain surface are analyzed and faithfully delineation, but the extent of terrestrial imaging is limited. It was necessary to crop the model and noise signals reach areas of considerable value. Deformation are generated on the edges of the model and the texture are blurred. We also tested the methods of intersection photogrammetry and manual referencing. It is difficult, none the less to look for identical points mainly on complex surfaces. It is necessary to use a high number of images, we are able to evaluate only the sharp and well defined edges. This disproportionately prolongs the time for evaluation. Evaluating topography using manual referencing is very difficult, time consuming and in many cases impossible. The starting point is the use of dense matching system.

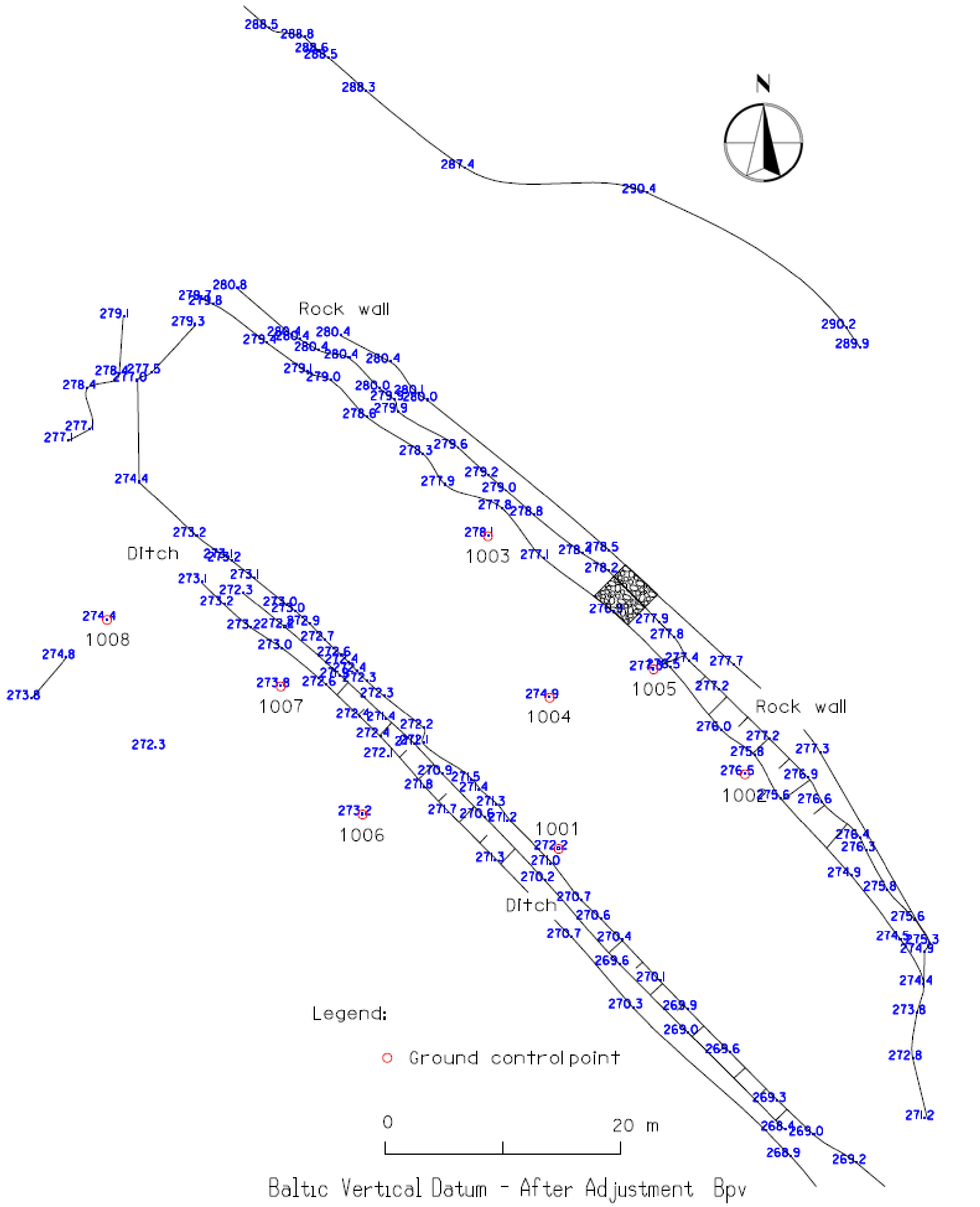

Fig 9. Part of vector drawings of assessed converging images

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