RESEARCH ON CREATING A DIGITAL PHOTOGRAMMETRIC MODEL BY USING DIFFERENT NUMBER OF CONTROL AND CHECK POINTS

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ABSTRACT. Improvement of the digital cameras and development of the digital image processing methods have led to the application of digital photogrammetry in underground mining. These days many studies are focused on the creation of digital models, which is one of the most important activities in mining. The reason is that a number of mine surveying and geological problems are solved through the models. A study related to the number of control points used in creating a digital photogrammetric model is presented in the paper. The obtained results are illustrated and analysed.

Keywords: close-range photogrammetry, digital photogrammetry, underground mine, control and check points

СЪЗДАВАНЕ НА ЧИСЛЕН ФОТОГРАМЕТРИЧЕН МОДЕЛ, ИЗПОЛЗВАЙКИ РАЗЛИЧЕН БРОЙ ОПОРНИ И КОНТРОЛНИ ТОЧКИ

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РЕЗЮМЕ. Усъвършенстването на апаратурата за заснемане и развитието на цифровите методи за обработка на изображения доведе до прилагането на цифровата фотограметрия в подземния добив. Все повече проучвания са насочени към създаване на числени модели което е една от най-важните дейности в минното дело, тъй като чрез тях се решават маркшайдерски и геоложки задачи. Представено е изследване свързано с броя на използваните опорни точки при създаване на числен фотограметричен модел. Получените резултати са онагледени и анализирани.

Ключови думи: близкообхватна фотограметрия, цифрова фотограметрия, подземен рудник, опорни и контролни точки

Introduction

The photogrammetric methods allow three dimensional models in underground mines to be generated. They are used as well to create digital models of galleries or parts of them, to calculate the volume of mined-out mass, to map the progress of mining activities, geological and structural mapping. These methods are applied also while observing walls and pillars. The number of used control points, their locations, as well as the root mean square error of the model and the points in the model itself are very important. The reason is because the solving of certain mine surveying and geological tasks requires accurate determination of coordinates of points, measurement of lengths, angles and other geometric features.

The deformation state of rock mass, galleries and pillars, and also their observation is a very important task for every underground mine. Most often they are followed by visual observations and specialised equipment. Even though, the subjectivity of surveillance techniques may be admitted to vague or incomplete analyses, due to the small amount of measured data. Observing changes with standard tools is costly and time-consuming, and the collected information is limited. An alternative to these methods is the use of digital photogrammetry for the exploration and monitoring of rock mass in underground mines, presented by Benton and colleagues. They have conducted two laboratories and field studies to prove that photogrammetry is a useful tool, which provides not only high precision but also occupational safety (Benton et al., 2016).

Other studies have evaluated the photogrammetric systems for ground control in underground mines. The research was conducted over a three-year period in Lucky Friday Mine, the United States, for the extraction of ore from rocks, which are susceptible to destruction, at a depth to 2,100 meters. The analysis of the results shows that the photogrammetric system is commensurate with conventional tools for measure of deformations, especially with regard to the interpretation of the potential movement in crossing the geological disturbance across the fault. The advantages of photogrammetry are presented, namely the increase of measurements compared to standard tools as crackmeter and the use of photogrammetric data together with 3D visualisation software for the synthesis and integration of complex information from a variety of sources, such as geology, mining technical conditions, seismicity and geotechnical toolkit (Benton et al., 2017).

Digital photogrammetric models help different specialists in mining companies - managers, engineers, miners, employees who are responsible for logistics, safety and health care. These models give a more comprehensive picture of the situation in the underground mine and they would be a suitable tool for both managers (investors, directors, managers) and employees in mining companies.

One of the main purpose of this research is to make comparison between points, whose coordinates are measured by a total station and the same points whose coordinates are received from the photogrammetric model. Another aim is to analyse both obtained results.

Experiments

In this study, data from a realized scientific research project at the University of Mining and Geology "St. Ivan Rilski" in 2018 is used. During the project a part of a gallery in the underground mine “Erma Reka”, Gorubso Zlatograd Corporation was shot by a photogrammetric method. The capture was executed by a Canon EOS 600D digital camera with a 16Mpix resolution and with the help of two external additional LED lamps. In order to create the model 314 photos were captured. There were 21 fixed points permanently marked on the researched object, which were evenly spaced. Their location is shown in Figure 1. The control points were measured with a total station – “Trimble S6” in a local coordinate system. The Russian software “Agisoft Photo Scan Professional Edition” processed the data, which were images in raw format. The resulting mean square error (absolute precision of the model) after the adjustment is 0.0072m and it is shown in Figure 2. In the same area a survey was conducted with a total station “Trimble S6” with built-in module for scanning of surface. A scanning step was selected - 0.50 m x 0.50 m (Begnovska, 2016). A comparison between the volume of mined-out mass from the model obtained from the photogrammetric shooting and the one from the geodetic survey was made. The difference in the volumes is in the range of 1.02%, which suggests that the proposed photogrammetric method can be used to calculate the volume of mined-out mass in underground mines. The results show that the presented methodology can be applied in real conditions for solving various mine surveying tasks: creation of three-dimensional mining models and graphic documentation, monitoring the progress of the exploitation activities, of volumes’ calculations, structural mapping and others (Gospodinova et al., 2018).

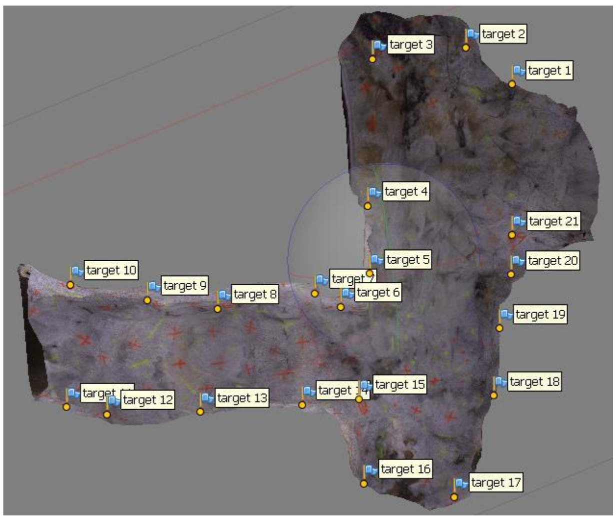

Fig. 1. Visualisation of a generated textured top-view photogrammetric model using 21 control points

Markers	X (m)	Y (m)	Z (m)	Accuracy (m)	Error (m)	Projectio
target 1	1998.082000	1001.688000	501.257000	0.005000	0.007195	39
target 2	1997.088000	1000.774000	501.936000	0.005000	0.003509	43
target 3	1997.070000	998.849000	501.933000	0.005000	0.003742	44
target 4	2000.318000	998.512000	500.553000	0.005000	0.003638	24
target 5	2001.512000	998.293000	501.724000	0.005000	0.003651	63
target 6	2002.147000	997.616000	501.578000	0.005000	0.007792	31
target 7	2001.951000	997.197000	500.695000	0.005000	0.011681	41
target 8	2001.799000	995.080000	501.881000	0.005000	0.010022	71
target 9	2001.505000	993.702000	501.416000	0.005000	0.008574	69
target 10	2001.111000	992.232000	500.645000	0.005000	0.008643	49
target 11	2003.567000	991.836000	500.922000	0.005000	0.003695	51
target 12	2003.620000	992.537000	502.137000	0.005000	0.007770	31
target 13	2004.032000	994.557000	500.913000	0.005000	0.008336	54
target 14	2004.108000	996.633000	501.264000	0.005000	0.012756	74
target 15	2004.022000	997.742000	501.961000	0.005000	0.007754	73
target 16	2005.795000	997.649000	501.896000	0.005000	0.006457	68
target 17	2006.272000	999.433000	502.143000	0.005000	0.008327	62
target 18	2004.450000	1000.554000	501.248000	0.005000	0.001633	54
target 19	2003.035000	1000.802000	501.562000	0.005000	0.006715	69
target 20	2002.031000	1001.218000	501.080000	0.005000	0.004029	45
target 21	2001.009000	1001.223000	502.375000	0.005000	0.003347	75
Total Error						
Control points					0.007247	

Fig. 2. Coordinates of the control points and mean square error of the photogrammetric model‘s adjustment

The main task of the present study is to identify the differences between geodetic and photogrammetric coordinates of control points located in a part of an underground mine gallery. The control points were obtained once by direct geodetic measurements with a total station “Trimble S6” and the second time they were measured by the created photogrammetric model of the same part.

A minimal number of required control points is used for the creation of the digital photogrammetric model – in this case 4 (3, 10, 17, 21). This will reduce the time to measure the control points and will lead to increasing the efficiency of the workflow. Figure 3 presents the location of control points in the model.

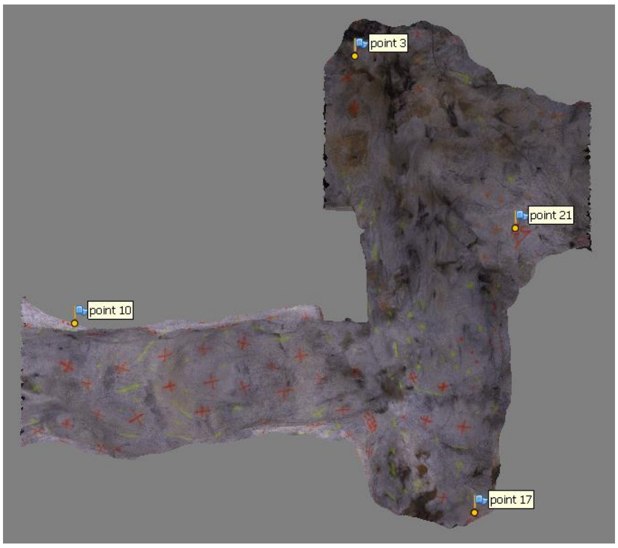

Fig. 3. Visualisation of a generated textured photogrammetric model using 4 reference points

Determination of the coordinate differences by manual measurement of the coordinates of the control points in the photogrammetric model

The photogrammetric model was generated by the "Agisoft Photo Scan Professional" software. The coordinates of 17 marked points in the photogrammetric model are measured. For the same point the geodetic coordinates are also measured. They serve as control points. Differences (errors) of x, y and z between the geodetic and photogrammetric coordinates are calculated and presented in Table 1.

Table 1.

№ of point	The values obtained from geodetic measurements			The values measured from the photogrammetric model			Errors		
	X_r [m]	Y_r [m]	Z_r [m]	$X_ф$ [m]	$Y_ф$ [m]	$Z_ф$ [m]	Δx_i [m]	Δy_i [m]	Δz_i [m]
1	1998.082	1001.688	501.257	1998.079	1001.683	501.252	0.003	0.005	0.005
2	1997.088	1000.774	501.936	1997.086	1000.770	501.933	0.002	0.004	0.003
4	2000.318	998.512	500.553	2000.318	998.508	500.551	0.000	0.004	0.002
5	2001.512	998.293	501.724	2001.513	998.291	501.726	-0.001	0.002	-0.002
6	2002.147	997.616	501.578	2002.140	997.620	501.586	0.007	-0.004	-0.008
7	2001.951	997.197	500.695	2001.946	997.192	500.694	0.005	0.005	0.001
8	2001.799	995.080	501.881	2001.791	995.076	501.892	0.008	0.004	-0.011
9	2001.505	993.702	501.416	2001.499	993.701	501.411	0.006	0.001	0.005
11	2003.567	991.836	500.922	2003.569	991.836	500.927	-0.002	0.000	-0.005
12	2003.620	992.537	502.137	2003.618	992.534	502.138	0.002	0.003	-0.001
13	2004.032	994.557	500.913	2004.032	994.556	500.915	0.000	0.001	-0.002
14	2004.108	996.633	501.264	2004.100	996.622	501.254	0.008	0.011	0.010
15	2004.022	997.742	501.961	2004.025	997.735	501.962	-0.003	0.007	-0.001
16	2005.795	997.649	501.896	2005.799	997.641	501.900	-0.004	0.008	-0.004
18	2004.450	1000.554	501.248	2004.442	1000.551	501.249	0.008	0.003	-0.001
19	2003.035	1000.802	501.562	2003.025	1000.802	501.562	0.010	0.000	0.000
20	2002.031	1001.218	501.080	2002.035	1001.221	501.076	-0.004	-0.003	0.004
number of control points							17	17	17
arithmetic mean [m]							0.003	0.003	0.000
standard deviation [m]							0.005	0.004	0.005
root mean square error by x, y and z [m]							0.005	0.005	0.005

In the same table arithmetic mean errors, standard deviation and root mean square errors are calculated. Table 2 and the following figures illustrate the results obtained as percentage ratio.

Table 2.

Differences	to 5 mm	To 10 mm	above 10 mm
Δx	70.59%	29.41%	0%
Δy	82.35%	11.77%	5.88%
Δz	82.35%	11.77%	5.88%

Determination of Δx, Δy and Δz

$$\Delta x_i = X_{\Gamma_i} - X_{\Phi_i};$$
$$\Delta y_i = Y_{\Gamma_i} - Y_{\Phi_i}; \quad (1)$$
$$\Delta z_i = H_{\Gamma_i} - H_{\Phi_i};$$

Xф, Yф and Hф are values for X, Y and H reported by stereo model, and Xr, Yr and Hr are values for corresponding points obtained from direct geodetic measurements.

Calculation of average arithmetic errors

$$\overline{x} = \frac{1}{n}\sum_{i=1}^{n} \Delta x_i \ ; \ \overline{y} = \frac{1}{n}\sum_{i=1}^{n} \Delta y_i \ ; \ \overline{z} = \frac{1}{n}\sum_{i=1}^{n} \Delta z_i; \quad (2)$$

where n - is the number of measurements, and Δxi, Δyi and Δzi are i- errors, where i = from 1 to n.

Calculation of the standard deviation

$$s_x = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(\Delta x_i - \overline{x})^2} \ ; \ s_y = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(\Delta y_i - \overline{y})^2} \ ;$$

$$s_z = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(\Delta z_i - \overline{z})^2} \quad (3)$$

where n - is the number of measurements, and Δxi, Δyi and Δzi are i-errors, $\bar{x}$, $\bar{y}$ and $\bar{z}$ are arithmetic mean errors and i = from 1 to n, where n- is the number of measurements.

Calculation of the root mean square error - m

$$m_x = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(x_{i(\Gamma)} - x_{i(\Phi)}\right)^2} \ ; \ m_y = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(y_{i(\Gamma)} - y_{i(\Phi)}\right)^2};$$

$$m_z = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(H_{i(\Gamma)} - H_{i(\Phi)}\right)^2} \quad (4)$$

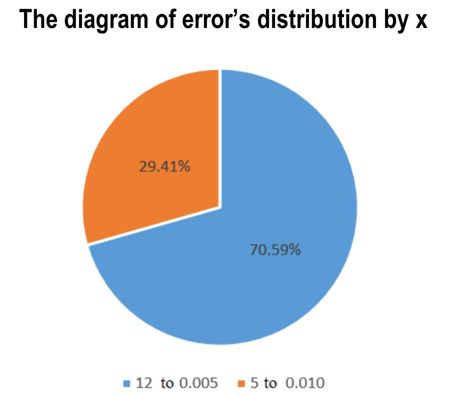

Fig.4. Number of errors' values by x in the respective interval and their percentage ratio of the total number of values.

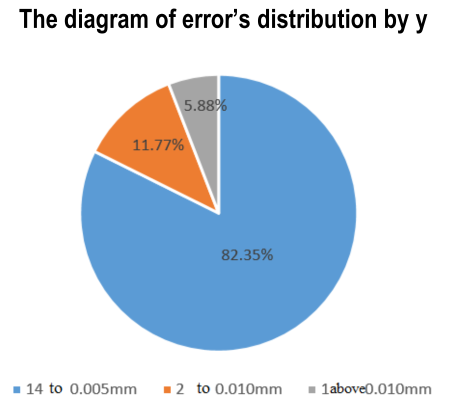

Fig. 5. Number of errors' values by y in the respective interval and their percentage ratio of the total number of values

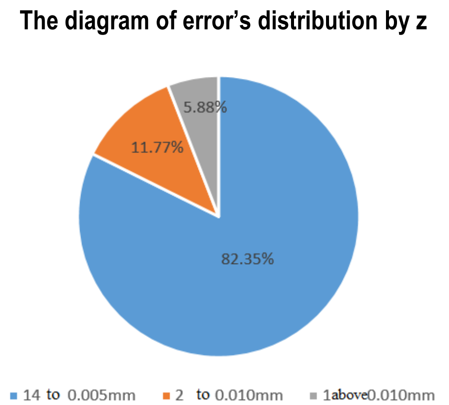

Fig.6. Number of errors' values by z in the respective interval and their percentage ratio of the total number of values.

Automatic determination of coordinate differences, using the same points as control points

In order to avoid subjectivity in marking the points' centre and the coordinates' measurement from the photogrammetric model, an automatic determination of the check points' coordinates is realized. For the creation of the photogrammetric model are used only four control points (3, 10, 17 and 21) and other 17 as check points. Figure 7 and Table 3 show the calculated errors by "Agisoft Photo Scan" photogrammetric software at check points' coordinates, arithmetic mean errors, standard deviation and mean square errors.

Label	X error (mm)	Y error (mm)	Z error (mm)	Total (mm)
target 11	-2.10849	-1.10916	10.413	10.6821
target 13	5.6361	0.475569	5.67418	8.01175
target 14	-2.46877	-13.5137	-3.5049	14.1774
target 15	1.59711	-8.74819	1.94044	9.10203
target 12	1.1671	2.44761	11.9427	12.2467
target 9	-6.6656	3.36296	-0.775175	7.50604
target 8	-9.18216	-0.367256	10.076	13.6372
target 7	-6.4127	6.63919	-2.88419	9.67058
target 6	-7.07436	1.90471	5.20107	8.98474
target 19	-8.15203	-2.38079	0.517456	8.50832
target 16	0.041933	-7.99581	2.783	8.46639
target 18	-1.84587	-2.12368	-1.49714	3.18727
target 20	2.00499	-2.66162	-4.04013	5.23707
target 1	1.23688	-10.2517	-2.63051	10.6558
target 2	-0.537735	-5.75093	-2.0317	6.12292
target 5	0.0996442	-5.34294	1.42034	5.5294
target 4	-1.96161	-1.80033	-2.84222	3.89453
Total	**4.50941**	**5.82541**	**5.33867**	**9.09789**

Fig. 7. Differences (errors) by x, y and z, and mean square error for each of them

Table 3.

number of control points	17	17	17
arithmetic mean [m]	-0.002	-0.003	0.002
standard deviation [m]	0.004	0.005	0.005
root mean square error by x, y and z [m]	0.005	0.006	0.005

Automatic determination of coordinate differences, using twice as many control points - in this case 8pcs

A study is conducted where a photogrammetric model is created by using twice more control points - in this case 8 pcs. (1, 3, 6, 10, 12, 15, 17, 21). These points are selected to be evenly distributed in the model. The purpose of the study is to determine the errors' values and to find out whether the increased number of control points has a significant impact on the root mean square error of x, y and z.

After the photogrammetric model with 8 control points and 13 check points is generated, it is found that there is no significant difference in the error's values compared to the model generated using 4 control points, as well as for arithmetic mean, standard deviation and root mean square error by x, y and z. This can be seen in Figure 8 and Table 4.

Label	X error (mm)	Y error (mm)	Z error (mm)	Total (mm)
target 11	-2.04356	-0.756156	3.09871	3.78813
target 13	6.15834	1.66331	0.242815	6.38363
target 14	-1.57844	-11.925	-7.30186	14.0717
target 9	-6.89568	4.19092	-5.85501	9.96972
target 8	-9.0065	0.513783	6.08469	10.8814
target 7	-6.3379	9.08692	-5.71897	12.4679
target 19	-7.03542	0.450182	0.305893	7.05644
target 16	1.80088	-6.74837	-0.595215	7.00985
target 18	-0.403272	0.702709	-2.46122	2.59115
target 20	2.68965	0.781438	-3.77146	4.69774
target 2	-1.21937	-2.52913	-0.203739	2.81512
target 5	0.496096	-3.2716	-0.12725	3.31145
target 4	-2.30994	1.36127	-4.20994	4.99124
Total	**4.64621**	**4.89697**	**3.97589**	**7.83424**

Fig. 8. Differences (errors) by x, y and z, and mean square error for each of them

Table 4.

number of control points	13	13	13
arithmetic mean [m]	-0.002	-0.000	-0.001
standard deviation [m]	0.004	0.005	0.004
root mean square error by x, y and z [m]	0.005	0.005	0.004

Conclusion

There is difference between points' coordinates obtained by accurate geodetic measurements and the ones received by the photogrammetric model. This difference is evaluated quantitatively by value of the arithmetic mean and the mean square error. The result of the comparisons shows that with the available image quality and the form of the captured object, the applied method ensures enormous accuracy when different tasks are solved. Moreover, when the conditions are suitable, the method may even claim to detect deformations in the support of mining excavations or mining equipment. Registering the effects of rock pressure on individual elements of excavations requires the determination of appropriate periodicity and the chosen shooting methodology to be followed each time.

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