DETERMINATION OF VERTICALITY AND STRAIGHTNESS OF BLIND SHAFT USING DIGITAL PHOTOGRAMMETRY

URČENÍ SVISLOSTI A PŘÍMOSTI ŠACHTICE POMOCÍ DIGITÁLNÍ FOTOGRAMMETRIE

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Abstract

The contribution results from the GA CR 105/09/P212 grant solution aiming at making a proposal of the measurement methodology and the data processing procedure for vertical mine workings. Resulting from the tests performed in a laboratory blind shaft n the building of the Rector's Office at the VSB-Technical University of Ostrava, a surveying rig, having been used till now, will be adjusted for measuring vertical mine workings using the digital photogrammetric method.

Taking digital images, a lot of means will occur to create applications for processing and automatic evaluation of verticality and straightness of individual objects of interest, or 3D modelling or visualization of shaft. Based on the results a mean error of the proposed measuring method will then be determined.

Abstrakt

Příspěvek vychází z řešení grantu GA ČR 105/09/P212, jehož cílem má být navržení metodiky měření a způsobu zpracování dat svislých důlních děl. Na základě testovacích zkoušek provedených ve cvičné šachtici v budově rektorátu na Vysoké škole báňské bude upravena doposud používaná měřická souprava pro zaměření svislých důlních děl metodou digitální fotogrammetrie.

S pořízením digitálních snímků se tak naskytne velké množství prostředků pro vytvoření aplikací ke zpracování a automatickému vyhodnocení svislosti a přímosti jednotlivých zájmových objektů nebo dokonce k provedení 3D modelování nebo vizualizace jámy. Z výsledků měření pak bude stanovena střední chyba navržené metody měření.

Key words: Digital photogrammetry, straightness, verticality, hoisting shaft.

1 INTRODUCTION

To measure vertical mine workings it is possible to use several technological procedures. To measure the lab blind shaft a method of single-image photogrammetry has been chosen using plumbs as fitting points. This method was developed in the eighties of the last century at the Mining Observation Base of VSB in Ostrava under the guidance of prof. Ing. Černý, CSc. in close contact with the Automation and Mechanization plant of OKR. The analog form of processing was successfully used till 1991 only, because the Foma company (supplier of film material for aerial photogrammetry) stopped to produce the needed high-sensitive material for process cameras. For this reason in 2003 at IGMS VSB-TU Ostrava a possibility was proposed to use a digital camera in measuring.

Within the doctoral thesis named Application of Digital Photogrammetry in Diagnostics of Mine Workings prepared by Ing. Dagmar Böhmová Ph.D., a new rig for measuring vertical mine workings using digital photogrammetry was designed and completed. This photogrammetric rig has been tested in the laboratory blind shaft in the rector office's building at the VSB-Technical University. To measure the blind shaft a method of single-image photogrammetry has been chosen using plumbs due to its simplicity and low costs as well.

This method consists in suspending the photogrammetry chamber *4* (Fig.1) beneath the hoisting cage, so its axis is upright. At the adequate distance a flash lighting device *8* is suspended under the photogrammetry chamber, emitting at the moment of the image exposure a horizontal beam *9* and creating in a given plane a narrow spot of light on the walls of lining. Horizontality of the light plane is provided by arrangement of hinge cables *5*, functioning as a pantograph. Images are captured gradually in upright distances with an interval of 510 m. In order to evaluate the straightness and verticality of the shaft lining, but especially guides, at least two plumb lines along the entire length of the area being measured are put down, on which in the light plane narrow spots *7* are lighted that are used during the evaluation as fitting points. Providing the camera's horizontal plane and the light fixture are adjusted correctly the cut of mine working being measured will be projected to the image plane in a ratio given by the focal length of lens of the photogrammetry camera and the distance of the light plane from the image one.

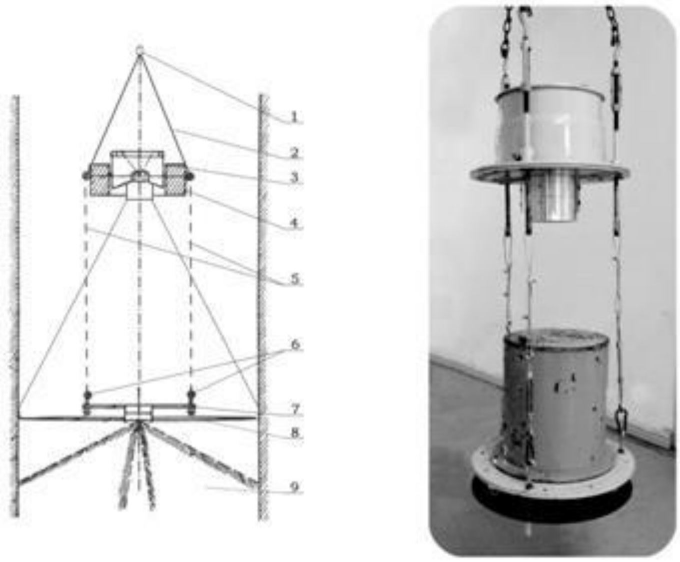

Fig. 1 Method of suspending the photogrammetric rig in the blind shaft

2 EXPERIMENTAL TESTS

In the laboratory blind shaft in the Rector Office's building at the VSB-Technical University a new-completed photogrammetric rig was tested. In this laboratory blind shaft (Fig.2), with dimensions of 73 x 142 cm and a depth of 35 m two plumb lines are dropped down. The operating procedure was aimed at verifying the functions of individual parts of the adapted equipment and ensuring the measurement accuracy by this method. In testing individual horizons of the blind shaft bottom were repeatedly scanned in the length of 20 m with an interval of 1 m.

Fig. 2 Laboratory blind shaft

2.1 Mounting works

The photogrammetric rig was freely suspended on a steel wire rope of an electric winch, which was attached to the steel structure above the upper blind shaft bank. This steel rope was measured out on one-meter sections and marked. On the suspension hook with a lock a hinge was created, to which the camera's carrier with the digital camera was attached. To the carrier steel cables were attached for gripping the lighting device within a given distance beneath the camera.

After connecting the lighting device the digital camera optical axis was rectified by turning it into a vertical position. Adjusting the levels on the lighting device into a balanced position also this device was rectified. Further, the digital camera was connected to the lighting device via a synchronizing cable. While measuring using the Fuji FinePix S2 Pro camera it was also necessary to connect this camera to a notebook via an interface of the FireWire cable.

2.2 Taking photos

Two calibrated digital cameras FujiFine Pix S2 Pro (6,1 MP) and Olympus E-20 (5,2 MP) were used for testing due to testing the measurement accuracy depending on the camera's resolving power. The beginning of the blind shaft bottom was always taken as the first measured horizon. This profile dimensions were measured using a steel tape.

The 20 m segment of the blind shaft was measured twice using the FujiFine Pix S2 Pro camera. The first series of images was acquired bottom-up, the second one from the top down. An example of the captured images of the laboratory blind shaft is shown in Fig. 3.

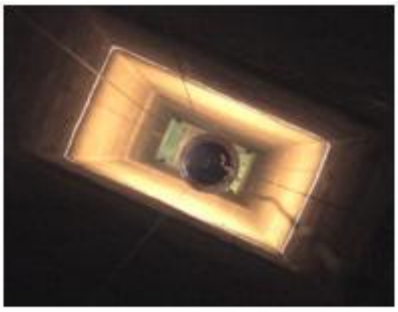

Fig. 3 Survey photo of the blind shaft

The FujiFine Pix S2 Pro camera was connected to a control unit (notebook) via the high-speed IEEE 1394 (FireWire) interface, allowing to use a special program (Camera shooting software) to trigger the exposure automatically as well as store the images on the hard disk of the computer. Using this connecting method the wireless data transition to the place of processing was tested, too. Using the RealVNC software the starting program in the notebook attached to the hinge of the photogrammetric rig was remotely controlled. At the moment of exposure it was possible to inspect immediately the captured images and shift to a horizon higher provided that the captured image was of high quality.

The third series of images was captured bottom-up using the Olympus E-20 camera. While measuring with Olympus E-20 the function of auto-sensing at the interval of 1 minute was used and the captured images were stored directly on the CompactFlash card.

2.3 Graphic processing

All captured images were first pre-processed using the FOTOM software developed by the Department of Informatics at the VSB-TU Ostrava under supervision of doc. Ing. Lačezar Ličev CSc. Using this program rectangular coordinates X,Y of all evaluated points were obtained from the images.

To facilitate the graphical display of the blind shaft profiles in the Microsoft Visual Basic For Application environment the applications *Profiles, Verticality and Straightness,* executable directly from the MicroStation V8 program, were created.

The *Profiles* application provides a graphical representation of blind shaft profiles viewed according to height horizons. To compare the accuracy it is possible to plot the matching profiles from individual series on each other and distinguish them by colours (Fig. 4a), plot the profiles of the entire blind shaft on each other (Fig. 4b), or create a „ wire model“ of the shaft (Fig. 4c).

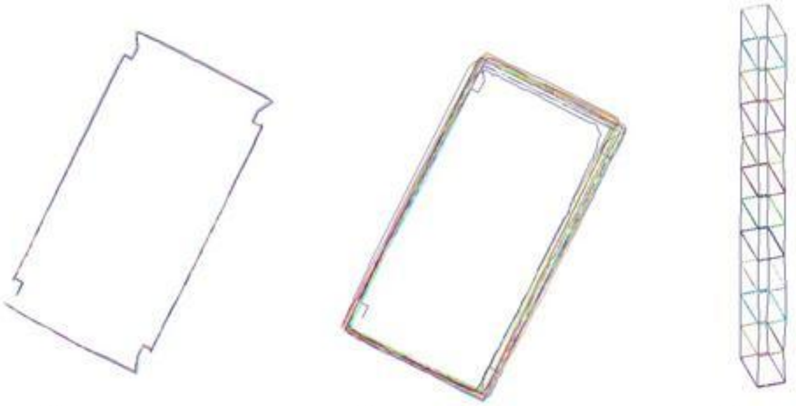

Fig. 4 Illustration of profiles using the *Profiles* application.

The *Verticality* application allows to represent the profile of verticality of the points of interest of the blind shaft. In Fig. 5 the verticality profiles from individual measurement series are plotted, for easier comparison of accuracy they are overplotted and colour-marked. As no guides or other objects are in the laboratory blind shaft, the blind shaft corners were chosen as the objects of interest.

These profiles can be graphically illustrated in either the X or Y directions in the measured horizons from the vertical, which goes through the first profile point of interest. The numeric value next to the curve is the size of deviation from the vertical, expressed in millimetres.

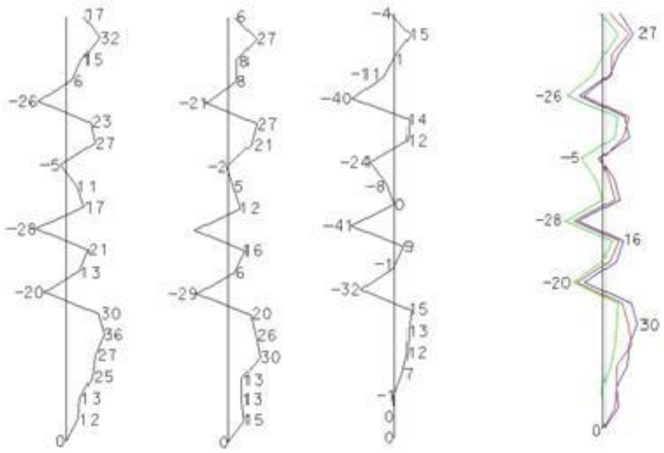

Fig. 5 Blind shaft verticality profile

The profile representation of the blind shaft straightness is shown in Fig. 6. These graphs are plotted after starting the *Straightness* application. The whole figure differs from the blind shaft verticality picture that instead of deviations from verticals the deviations from the line connecting points of the first and last profile are illustrated. The deviations are again given in millimetres.

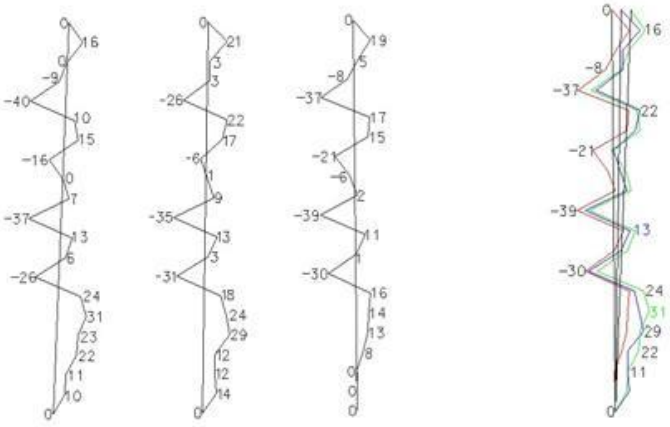

Fig. 6 Blind shaft verticality profile

For a classical circular shaft also the dimension (radius) of the shaft target would be further determined using several steps. First, the local dimension of the blind shaft is calculated, followed by the calculation of radius on the horizon, and finally the calculation of the shaft radius. Further, it is also possible to track deviations in the shape of the shaft target.

2.4 Measurement accuracy

To determine the accuracy of the method used, while evaluating the blind shaft lining, three image series were captured in identical height horizons. As no actual dimension of the blind shaft on the measured horizons was known, the mean error of a single measurement was calculated as the mean error of arithmetic mean according to the formulas:

$$m_x = \pm \frac{m}{\sqrt{n}} \qquad \text{where} \qquad m = \pm \sqrt{\frac{[vv]}{(n-1)}} \qquad (1)$$

where:

m_x - mean error of arithmetic mean [m],

m - mean error of one measurement on a horizon [m],

v_i - corrections [m].

Whereas, we were interested in the mean error of individual profile measurements, the mean error of a single measurement was calculated for each horizon separately and [vv] was computed as a sum of differences of arithmetic means of the measured distances on individual horizons and the distances found out from images.

The final values are shown in Tab. 1. It is evident from this table that the mean errors of a single measurement ***m*** ranged from 2 ÷ 10 mm and the mean errors of arithmetic mean $\boldsymbol{m_x}$ were in the range of 1 ÷ 3 mm.

Tab. Mean errors of a single measurement of height horizons (level, first series [m], second series [m], third series [m], diameters [m], m of level, mx of level)

	první série [m]				druhá série [m]				třetí série [m]				průměry [m]				m patra	mx patra
patro	s12	s23	s34	s41	s12	s23	s34	s41	s12	s23	s34	s41	s12	s23	s34	s41	[m]	[m]
1	1,381	0,708	1,391	0,690	1,389	0,712	1,394	0,693	1,386	0,705	1,388	0,685	1,385	0,708	1,391	0,689	±0,003	±0,001
2	1,427	0,727	1,425	0,699	1,431	0,728	1,428	0,696	1,439	0,722	1,428	0,699	1,432	0,726	1,427	0,698	±0,003	±0,001
3	1,435	0,723	1,423	0,715	1,433	0,724	1,419	0,712	1,434	0,724	1,428	0,710	1,434	0,724	1,423	0,712	±0,002	±0,001
4	1,421	0,724	1,411	0,734	1,425	0,716	1,438	0,740	1,436	0,732	1,422	0,746	1,427	0,724	1,424	0,740	±0,008	±0,002
5	1,415	0,717	1,419	0,734	1,420	0,728	1,415	0,734	1,412	0,707	1,417	0,739	1,416	0,717	1,417	0,736	±0,005	±0,001
6	1,421	0,737	1,421	0,742	1,421	0,729	1,411	0,734	1,419	0,729	1,413	0,736	1,420	0,732	1,415	0,737	±0,004	±0,001
7	1,418	0,722	1,426	0,720	1,437	0,734	1,434	0,743	1,424	0,724	1,430	0,722	1,426	0,727	1,430	0,728	±0,008	±0,002
8	1,416	0,693	1,411	0,691	1,419	0,684	1,406	0,682	1,411	0,693	1,413	0,698	1,415	0,690	1,410	0,690	±0,005	±0,001
9	1,413	0,704	1,396	0,715	1,408	0,705	1,395	0,722	1,400	0,701	1,381	0,713	1,407	0,703	1,391	0,717	±0,005	±0,001
10	1,413	0,718	1,395	0,729	1,386	0,705	1,370	0,715	1,401	0,717	1,392	0,728	1,400	0,713	1,386	0,724	±0,009	±0,003
11	1,435	0,704	1,423	0,690	1,426	0,705	1,408	0,695	1,417	0,689	1,409	0,682	1,426	0,699	1,413	0,689	±0,007	±0,002
12	1,432	0,738	1,444	0,721	1,433	0,743	1,450	0,725	1,433	0,737	1,433	0,721	1,433	0,739	1,442	0,722	±0,004	±0,001
13	1,427	0,738	1,446	0,717	1,445	0,748	1,452	0,722	1,425	0,740	1,440	0,715	1,432	0,742	1,446	0,718	±0,006	±0,002
14	1,386	0,693	1,371	0,703	1,387	0,699	1,377	0,701	1,383	0,694	1,375	0,691	1,385	0,695	1,374	0,698	±0,003	±0,001
15	1,412	0,705	1,405	0,699	1,427	0,708	1,399	0,704	1,415	0,703	1,395	0,703	1,418	0,705	1,400	0,702	±0,004	±0,001
16	1,401	0,725	1,398	0,709	1,405	0,720	1,405	0,718	1,395	0,718	1,398	0,705	1,400	0,721	1,400	0,711	±0,004	±0,001
17	1,354	0,625	1,347	0,662	1,337	0,648	1,362	0,665	1,362	0,613	1,352	0,659	1,351	0,629	1,354	0,662	±0,010	±0,003
18	1,427	0,689	1,430	0,703	1,417	0,691	1,428	0,698	1,427	0,692	1,441	0,701	1,424	0,691	1,433	0,701	±0,004	±0,001
19	1,455	0,690	1,441	0,712	1,454	0,693	1,439	0,711	1,443	0,691	1,433	0,703	1,451	0,691	1,438	0,709	±0,004	±0,001
20	1,411	0,703	1,404	0,718	1,424	0,701	1,404	0,726	1,416	0,697	1,403	0,721	1,417	0,700	1,404	0,722	±0,004	±0,001
21	1,449	0,731	1,446	0,744	1,448	0,730	1,447	0,743	1,437	0,723	1,441	0,734	1,445	0,728	1,445	0,740	±0,004	±0,001

Greater mean errors of individual horizons could be caused by inaccurate move of the rig to a height horizon, vibrations of the hinge of the photogrammetric rig, or unwanted vibrations of plumb wires. Since there are no significant points during the evaluating of peripheral masonry of the blind shaft, the higher mean errors can be caused also by the fact that the surveyed points on the peripheral wall of the blind shaft of a single image are not usually identical to the points surveyed on an image of another series. Although the maximum value of mean measurement errors varies about 1cm, this value is satisfactory in evaluating of the shaft lining.

To determine the accuracy of the single-image photogrammetric method for evaluating the shaft lining, 20 images were captured in the lowest (first) horizon. As the horizon was re-measured using a steel tape, thus the actual dimension of the blind shaft on this horizon was known (Fig. 7), the mean error of a single measurement on the first horizon was calculated from the determined actual errors:

$$m_x = \pm \frac{m}{\sqrt{n}} \qquad \text{where} \qquad m = \pm \sqrt{\frac{[\varepsilon\varepsilon]}{n}}$$

where:

m_x - mean error of arithmetic mean [m],

m – mean error of a single measurement on the first horizon [m],

ε_i - actual errors [m].

The mean error of a single measurement was then calculated for all dimension on an image and $[\varepsilon\varepsilon]$ was calculated as a sum of differences of actual dimensions on the first horizon and dimensions determined from images.

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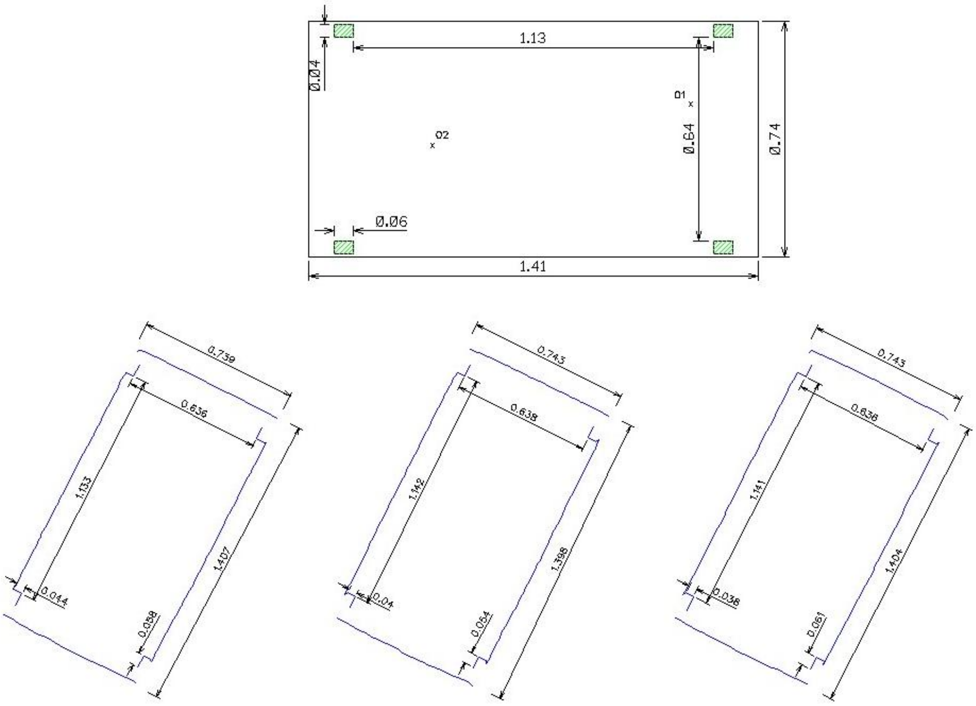

Fig. 7 Comparison of dimensions of the blind shaft and projected profile

The final values are shown in Tab. 2. It is evident from this table that the mean errors of a single measurement ***m*** ranged from 2 ÷ 4 mm and the mean errors of arithmetic mean $\boldsymbol{m_x}$ were about 1 mm.

Tab. 2 Mean errors of a single measurement on the first horizon (evaluated distances (images) [m], distance difference (tape-image) [m], length, image 1 … image 20, measured distance)

	délka	sním 1	sním 2	sním 3	sním 4	sním 5	sním 6	sním 7	sním 8	sním 9	sním 10	sním 11	sním 12	sním 13	sním 14	sním 15	sním 16	sním 17	sním 18	sním 19	sním 20	měřená vzd
vyhodnocené vzdálenosti (snímky) [m]	s 12	0,057	0,056	0,055	0,055	0,055	0,055	0,055	0,057	0,057	0,056	0,055	0,057	0,060	0,057	0,056	0,056	0,057	0,057	0,056	0,058	0,058
	s 23	0,038	0,037	0,039	0,039	0,038	0,038	0,038	0,037	0,037	0,038	0,039	0,040	0,037	0,037	0,037	0,039	0,039	0,040	0,040	0,037	0,038
	s 45	0,034	0,035	0,036	0,037	0,036	0,037	0,037	0,037	0,036	0,037	0,038	0,034	0,039	0,037	0,036	0,036	0,036	0,037	0,035	0,037	0,038
	s 56	0,057	0,057	0,056	0,055	0,057	0,057	0,056	0,056	0,057	0,056	0,055	0,057	0,054	0,055	0,055	0,057	0,055	0,056	0,055	0,055	0,058
	s 78	0,055	0,065	0,058	0,055	0,056	0,060	0,058	0,057	0,059	0,062	0,056	0,056	0,054	0,056	0,056	0,058	0,056	0,057	0,056	0,063	0,058
	s 89	0,037	0,037	0,036	0,036	0,037	0,037	0,037	0,037	0,038	0,037	0,039	0,036	0,036	0,037	0,038	0,038	0,037	0,037	0,036	0,038	0,038
	s 1011	0,037	0,037	0,036	0,035	0,037	0,037	0,037	0,036	0,036	0,038	0,037	0,037	0,036	0,036	0,037	0,036	0,038	0,034	0,037	0,036	0,038
	s 1112	0,057	0,057	0,057	0,058	0,057	0,058	0,057	0,057	0,058	0,054	0,057	0,057	0,058	0,057	0,056	0,057	0,057	0,055	0,058	0,057	0,058
	s 25	1,133	1,133	1,137	1,136	1,128	1,137	1,141	1,130	1,132	1,136	1,134	1,134	1,136	1,132	1,135	1,135	1,137	1,134	1,133	1,140	1,138
	s 58	0,637	0,634	0,636	0,635	0,633	0,635	0,639	0,632	0,634	0,635	0,631	0,635	0,634	0,633	0,636	0,635	0,636	0,634	0,631	0,636	0,635
	s 811	1,133	1,135	1,137	1,135	1,132	1,139	1,143	1,133	1,134	1,137	1,135	1,137	1,140	1,135	1,138	1,137	1,140	1,137	1,138	1,140	1,140
	s 211	0,635	0,635	0,636	0,636	0,633	0,637	0,639	0,635	0,635	0,635	0,635	0,636	0,639	0,634	0,636	0,636	0,636	0,638	0,632	0,639	0,635
	s 28	1,303	1,303	1,305	1,305	1,298	1,306	1,311	1,299	1,300	1,304	1,302	1,305	1,306	1,300	1,305	1,304	1,307	1,303	1,299	1,309	1,305
	s 511	1,296	1,296	1,300	1,298	1,300	1,301	1,306	1,295	1,297	1,300	1,296	1,297	1,302	1,296	1,299	1,299	1,301	1,300	1,298	1,303	1,303
rozdíl vzdálenosti (pásmo - snímek) [m]	s 12	0,001	0,002	0,003	0,003	0,003	0,003	0,003	0,001	0,001	0,002	0,003	0,001	-0,002	0,001	0,002	0,002	0,001	0,001	0,002	0,000	
	s 23	0,000	0,001	-0,001	-0,001	0,000	0,000	0,000	0,001	0,001	0,000	-0,001	-0,002	0,001	0,001	0,001	-0,001	-0,001	-0,002	-0,002	0,001	
	s 45	0,004	0,003	0,002	0,001	0,002	0,001	0,001	0,001	0,002	0,001	0,000	0,004	-0,001	0,001	0,002	0,002	0,002	0,001	0,003	0,001	
	s 56	0,001	0,001	0,002	0,003	0,001	0,001	0,002	0,002	0,001	0,002	0,003	0,001	0,004	0,003	0,003	0,001	0,003	0,002	0,003	0,003	
	s 78	0,003	-0,007	0,000	0,003	0,002	-0,002	0,000	0,001	-0,001	-0,004	0,002	0,002	0,004	0,002	0,002	0,000	0,002	0,001	0,002	-0,005	
	s 89	0,001	0,001	0,002	0,002	0,001	0,001	0,001	0,001	0,000	0,001	-0,001	0,002	0,002	0,001	0,000	0,000	0,001	0,001	0,002	0,000	
	s 1011	0,001	0,001	0,002	0,003	0,001	0,001	0,001	0,002	0,002	0,000	0,001	0,001	0,002	0,002	0,001	0,002	0,000	0,004	0,001	0,002	
	s 1112	0,001	0,001	0,001	0,000	0,001	0,000	0,001	0,001	0,000	0,004	0,001	0,001	0,000	0,001	0,002	0,001	0,001	0,003	0,000	0,001	
	s 25	0,005	0,005	0,001	0,002	0,010	0,001	-0,003	0,008	0,006	0,002	0,004	0,004	0,002	0,006	0,003	0,003	0,001	0,004	0,005	-0,002	
	s 58	-0,002	0,001	-0,001	0,000	0,002	0,000	-0,004	0,003	0,001	0,000	0,004	0,000	0,001	0,002	-0,001	0,000	-0,001	0,001	0,004	-0,001	
	s 811	0,007	0,005	0,003	0,005	0,008	0,001	-0,003	0,007	0,006	0,003	0,005	0,003	0,000	0,005	0,002	0,003	0,000	0,003	0,002	0,000	
	s 211	0,000	0,000	-0,001	-0,001	0,002	-0,002	-0,004	0,000	0,000	0,000	0,000	-0,001	-0,004	0,001	-0,001	-0,001	-0,001	-0,003	0,003	-0,004	
	s 28	0,002	0,002	0,000	0,000	0,007	-0,001	-0,006	0,006	0,005	0,001	0,003	0,000	-0,001	0,005	0,000	0,001	-0,002	0,002	0,006	-0,004	
	s 511	0,007	0,007	0,003	0,005	0,003	0,002	-0,003	0,008	0,006	0,003	0,007	0,006	0,001	0,007	0,004	0,004	0,002	0,003	0,005	0,000	
stř.ch. [m]	m	±0,003	±0,003	±0,002	±0,003	±0,004	±0,001	±0,003	±0,004	±0,003	±0,002	±0,003	±0,003	±0,002	±0,003	±0,002	±0,002	±0,002	±0,002	±0,003	±0,002	
	mx	±0,0009	±0,0009	±0,0005	±0,0007	±0,0011	±0,0004	±0,0008	±0,0011	±0,0009	±0,0006	±0,0008	±0,0007	±0,0006	±0,0009	±0,0005	±0,0005	±0,0004	±0,0007	±0,0009	±0,0006	

3 CONCLUSION

The subject of the solved project is to adapt the photogrammetric rig to allow using a non-metric digital camera for measuring vertical mine workings. Due to this requirement, a new hinge for the camera attachment was created and lighting device adapted and interconnected with the camera via a synchronizing cable. Functionality of this adapted photogrammetric rig was tested in the laboratory blind shaft in the building A at VSB-TU Ostrava.

To evaluate individual points and objects of interest, the FOTOM system was used, from which global coordinates of the evaluated objects and points were obtained. These coordinates were then loaded into the MicroStation V8 program using the created application *Vyhodnoceni.Jam (Shaft.Evaluation)*. Graphical outputs for the representation of verticality and straightness of the blind shaft were plotted using the applications Svislost (Verticality) and Primost (Straightness).

The used photogrammetric method allows to obtain an extensive set of information, which is permanently recorded on the survey photo. The data stored in a digital form are not subject to any geometric changes caused by changes in temperature or humidity, which allows to perform the re-measurement of individual images and possibly additional evaluation of other parameters characterizing the mine working. Moreover, it is possible to capture in a documentary way the current technical condition of the shaft to allow a complex view of temporal and spatial behaviour of deformations in mine working.

The test experiments confirmed the assumption that the accuracy of measurement using 6 MP digital camera will be the same as with 5 MP digital camera.

As the diameter of the adapted photogrammetric rig is 32 cm it is possible to use it also for photographic documentation of large-diameter boreholes. The results of the test trials showed that the photogrammetric rig is suitable for obtaining information on the actual shape of the shaft with cm accuracy. However, so that we could to use the rig in practice, it is highly desirable the measurement to be retested many times in the pit of some active shaft.

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