Terrestrial photogrammetry at the quarry and validating the accuracy of slope models for monitoring their stability

Dima Ozhygin¹, Václav Šafář², Dmitrij Dorokhov³, Svetlana Ozhygina¹, Sergey Ozhygin¹, Hana Staňková²

¹Karaganda State Technical University, 100027 Karagandy, Kazakhstan
²VSB Technical university of Ostrava, FMG, Department of Geodesy and Mine Surveying, Czech Republic

vaclav.safar@vsb.cz

Abstract. The paper is devoted to the application of photogrammetry in surveying and geomechanical studies of the state of stability of slopes in a quarry. For deep quarries a particularly important task is to ensure the stability of the slopes of the benches. The purpose of this study is to improve the survey techniques of the slopes using terrestrial photogrammetry, the establishment of the values of the basic errors in the positioning of cameras in local geodetic network. The results of photogrammetric measuring data processing, which are the coordinates of the slope points and its elements, point cloud, surface model, volume and area data, improve the quality of geomechanical monitoring at mining enterprises and provide increase safety of mining operations. The proposed method of survey consists in positioning images (projection centres) in the system of the geodetic reference network by measuring with an electronic total station. Established during the study was dependence of the accuracy of the coordinates of the three-dimensional model of the slopes on the distance between the camera and the total station, between the camera positions in a pair of images. The article contains the results of the practical implementation of the proposed survey method, the results of experiments performed for the purpose of comparison with an alternative measurement method, which was a survey by a total station, graphs of dependencies describing the effect of measurement parameters on the accuracy of work performed. The article is also supplemented by a theoretical analysis of the use of UAVs in the use of work to determine of stability of slopes in a quarry, which is based on the authors' experience with the use of UAVs in open pit mines. In this theoretical comparison, the emphasis is mainly on the operability of the use of UAV, which in the case of open pit mines creating a practically stable wind vortex with a speed higher than the allowed speed of operation rotors UAVs.

1. Introduction

For deep quarries, an important task is to ensure stability of the slopes of ledges in accordance with the design resulting position of the perimeter of the mining horizons. The extension of the operating life of deep quarries, the excavate of mineral reserves and the increase in design depth of the quarry are accompanied by changes in the design of the perimeters to the final position. The impact of mining and the expansion of the mining area leads to the opening and formation of new rock jointing and blocks, which reduces stability of the slopes. As part of survey monitoring of the state of sides and ledge slopes in a quarry to ensure their stability is required a quality inspection of slope and analysis of actual state of quarry slopes.
According to [1], the condition of near-surface mine arrays of the quarry can be studied with laser scanning. Laser scanning technology allows measurements with millimeter accuracy sufficient to detect displacements in the horizontal and vertical planes [2]. The use of a laser scanner, according to [3], makes it possible to identify rock jointing on the surface of a slope, as well as to identify landslides as well as accumulation of rock blocks. Scan data obtained from various sites during the office data processing are combined into a single three-dimensional point cloud [4]. Another example of technology for monitoring the status of slopes, which has been widely used in mining, is ground interferometry [5] and satellite interferometry [6]. These survey technologies are characterized by productivity and a large amount of data, but similar results, in the form of three-dimensional models of slope surfaces, can be achieved using photogrammetric technology.

Photogrammetry allows one to interpret spatial information in a given coordinate system and to measure the coordinates of individual points. The basic of photogrammetry technology is to capture a real object in several images taken from different angles, to process the obtained images using specialized software which independently forms connections between images and creates the basis for a three-dimensional object. The advantage of the method is the ability to convey the smallest irregularities and details of the object (cavities, detailed texture of rocks in the excavated area,), without using expensive laserscanning equipment for 3D modelling of quarries. Photogrammetric methods also allow reconstructing large-sized objects, and exploring structures in a dynamic state [7].

The purpose of this study is to improve methods of surveying slopes of ledges using terrestrial photogrammetry. The study discusses the limit conditions for the use of terrestrial photogrammetry, the achievable measurement accuracy and supporting terrestrial photogrammetry by electronic total station.

2. Previous work
Recently, specialists in the fields of practical geodesy and mine surveying have been becoming more interested in remote measurement and photogrammetry technologies. This is due to the development of technologies and hardware capabilities in the field of digital photography, satellite technologies, and photographic images processing software.

The issues of the accuracy of determining geodetic coordinates during remote sensing and the estimation of the accuracy of models constructed from pairs of images of different origin are considered in [8] and [9]. The publications [10] and [11] describe the placement of a digital photogrammetric camera on an unmanned aerial vehicle equipped with a single-phase GPS receiver, which allows one to determine the coordinates of the center of the camera. The authors propose methods of calibration and synchronization taking into account the residual electronic delay between the sensors.

In the work [12] authors discuss in detail the sources of errors in performing photogrammetric surveys and propose methods of image processing. Among the main sources of errors, optical distortions stand out, which are corrected by means of the first, second, and third order polynomial transformations. Polynomial transformation is the most widely used method of mathematically transforming file coordinates to emulate coordinates. Polynomial transformation allows one to apply constants and variables to the original coordinates of the file to get the true coordinates. Polynomial equations are determined by their order - the number of variables allowed in the equation. The higher the order, the more complicated the equation becomes. A higher-order polynomial equation can eliminate more complex image distortions than lower-order polynomials. Unfortunately, the higher the order of polynomial, the more manual control is required. The authors [12] recommend using the lowest polynomial order, which gives acceptable errors, and allows for maximum automation of image processing. The processing order depends on the degree of image distortion.
In the study [13] authors describe a study of the process of creating 3D terrain models using an unordered set of images using digital photogrammetry methods. This process includes two stages: 1) image orientation in a single coordinate system; 2) the generation of a dense cloud of points representing a digital surface model [13].

2.1 Materials and methods
Photogrammetry is characterized by high productivity and simplicity of field work. A digital camera and a means of determining the position of the camera and ground control points are required (in this study an electronic total station is used for that).

The essence of the terrestrial photogrammetric measuring is shown in figure 1 [14]. According to the figure 1, in the process of measuring and subsequent processing of digital photographic images are calculated elements of internal and external orientation.

![Figure 1. Fundamentals of terrestrial photogrammetric measuring methods [14]](image)

Elements of interior orientation include: f - focal length, the coordinates of the principal point O \((x_0, z_0)\) in the coordinate system of the image \(x_1x_2z_1z_2\) and distortions of image. Elements of external orientation include: the coordinates of the projection centre S \((X_S, Y_S, Z_S)\) that form the basis \(B_0\), the directional angle of the optical axis S - O - \(\alpha\), the angle of inclination of the optical axis S_0 - \(\omega\), the angle of rotation of the image \(\chi\), the internal horizontal angles between the basis \(B_0\) and optical axis S_0 - \(\psi\).

Based on the image shown in figure 1, point M on the slope is displayed in two image as points \(m_1\) and \(m_2\). Point M and similar points are tie points. These points, identified by special algorithms similar to those described earlier, allow us to calculate the internal orientation elements of the image and some of the external elements during processing images in photogrammetric software. If the true coordinates of the points S are uncertain, then the software will calculate them in the conditional system relative to the tie points. Thus, the three-dimensional model of the slope of the ledge will be oriented in the relative coordinate system. One way to obtain a three-dimensional model in a national (or local) coordinate system is to determine the coordinates of the S points, ie the coordinates of the camera position (projection centre). For these purposes, it is proposed to use an electronic total station and reflective foil stuck on the body of a digital camera, because electronic total stations are the most common type of geodetic equipment in mining enterprises. The design of the surveying rod is shown in figure 2.

The process of quarry slope photogrammetric surveying consists of moving the surveying rod with the camera along the slope along pickets located at a distance equal to \(B_0\). At each picket, a quarry
slope image is taken and the coordinates of the camera S are determined by total station using measurements from the reflector (S’coordinates).

![Figure 2. Surveying rod with camera](image)

A minimum of three reference points (camera position coordinates) are required by photogrammetric programs to specify a coordinate system, optimize photo alignment and measure distances. During image processing and building a three-dimensional model, the obtained coordinates are assigned to the corresponding images as a result of which a detailed three-dimensional model of the slope in true coordinates and the texture of the slope is rebuilt. The resulting model can be used for further geomechanical studies of the state of the slope (e.g. fracture, geometric parameters of the slope, weakening surfaces, manifestations of deformations, determinate volume of material in the landslide [15].

2.2 Validating of measurement and modeling accuracy

Based on the recommendations for the production of surveying operations in the extraction of solid minerals, the accuracy of the survey work is determined by the requirement for the error in determining the points of the survey networks relative to the nearest points of the surveying reference geodetic network. According to instructions for surveying works limit error should not exceed 0.4 mm in plan, which for a scale of 1: 1000 is 0.4 m in plan and 0.2 m in elevations [16] and [17]. Thus, it is necessary to establish the conformity of the proposed method for surveying quarry slopes with these accuracy requirements. For this purpose the process of the occurrence of errors is considered.

According to [13], the first step in creating a three-dimensional terrain model from digital images is to orient the images in a single coordinate system. This process can be carried out both with the introduction of the known coordinates of the positions of the centers of the camera S into the calculations, and without them - in the conditional system, based only on the internal orientation elements of the images calculated from the common tie points m1, m2, m3 ... In this case, the images
and the model as a whole will not be correctly oriented in space, but the bases \( B_0, B_1, B_2 \ldots \) will be characterized by a length - \( B \), \( m \), which will be as close as possible to the true length. Only the error of identifying tie points - \( m_{\text{ref,p}} \), the error of optical distortions of image distortion [12] - \( m_{\text{opt.dist}} \) will take part in determining its value. To assess the accuracy of the proposed method, the influence of these errors can be considered minimal, since the pictures of the slopes of the ledges are made from a relatively close distance (limited by the width of the ledge), as a result of which the pictures are characterized by excessive detailing, large scale and small distances between projection centers.

The following sources of errors are the errors in determining the coordinates of an electronic total station:

1. Root-mean-square error of the method of polar coordinates \( m_{\text{pol.c.}} \), \( m \) is determined by the equation (1), measurements are made in one step \( n = 1 \), with \( L \) - the length of the measured side.

\[
m_{\text{pol.c.}} = \frac{1}{\sqrt{n}} \sqrt{\sum m_i^2 + \left( \frac{m_\beta}{\rho} \right)^2 L^2}, \ m
\]

where \( m_\delta \) – the error of distance measurement based on the characteristics of the total station is taken equal \( 5\cdot10^{-3} \) m;

\( m_\beta \) – the root-mean-square error of angle measurement equal to \( 5^\prime\) (Nikon NPL-352);

\( \rho \) – constant equal to \( 206265^\prime\).

2. The error arising due to the mismatch of the position of the center of the film reflector \( S' \) on the camera body and the true optical center of the camera \( S \) - \( m_{\text{ref..}} \). This error is determined by the dimensions of the camera body. In this study, a camera (NIKON D3300) with dimensions of 124mm, 98mm, 76 mm is used. In this study, the value of \( m_{\text{ref..}} \) is taken to be a maximum of 124 mm, to establish exactly the maximum possible errors.

According to figure 2, during the photogrammetric survey, \( m_{\text{pol.c.}} \), \( m_{\text{ref..}} \) cause coordinate offsets \( \Delta X, \Delta Y, \Delta Z \) of two points of the basis \( (S_1 \text{ and } S_2) \) which in turn affect the accuracy of indirectly determining the length of the bases \( B \) - \( m_B \) (equation 2) by solving the inverse geodesic equation, the directional angles of the optical axes of \( S_O \) images are \( \alpha \), the tilt angles of the \( S_O \) axes are \( \omega \), and the rotation angles of the image are \( \chi \), after entering some correction values of \( \Delta B, \Delta \alpha, \Delta \omega, \Delta \chi \) respectively

\[
m_y = \sqrt{2(m_{\text{pol.c.}} + m_{\text{ref..}})}, \ m
\]

The source [14] provides equations (3, 4, 5) for calculating the errors in determining the coordinates of points on a terrain or object during phototheodolite surveying without reflectors. In the phototheodolite survey, angles and distances are measured simultaneously during taking images, which corresponds to linear and angular measurements performed according to the proposed method using an electronic total station and reflectors on the camera.

\[
m_{x,c} = \sqrt{\left( \frac{m_x X_i}{B'^2} \right)^2 + \frac{X_i m_x}{B'^2} \sin \psi + \left( \frac{m_y}{f} \right)^2 Y^2}, \ m
\]
where \( m_{X,G} \) – the error in determining the geodetic coordinates (abscissa) of points of the three-dimensional model, m;

\( m_{Y,G} \) – the error in determining the geodetic coordinates (ordinates) of points of the three-dimensional model, m;

\( m_{Z,G} \) – the error in determining the absolute heights of the points of the three-dimensional model, m;

\( m_p \) – root-mean-square error of determination of longitudinal parallax, m, is determined by the expression (6);

\[
m_p = f m_y \ , \ m
\]  

\( X_1 \) – the abscissa of point in the left image, m;

\( f \) – focal length is taken equal 1.8·10^{-2} m;

\( m_{n.m} \)– root-mean-square error of determining the difference in absolute elevations by the method of trigonometric leveling by an electronic total station, according to [18], is found from the equation (7), m;

\( Y \) – ordinate, m, tie point M in the system \( S_{1XYZ} \) (figure 1);

\( \psi \) – internal horizontal angle between the basis \( B_0 \) and optical axis \( S_0 \) from the left edge of the basis, °;

\( m_x \) – root-mean-square error of definitions of abscissas of a point of a image \( S_1 \), m, taken equal to \( m_B \), since the coordinates of point \( S_1 \) are determined directly by the total station from the reflector, to indirectly determine the length of the basis;

\( Z_1 \) – elevation of the point in the left picture, m;

\( m_{z1} \)– root-mean-square error in determining the mark of the image point \( S_1 \), m, is taken equal to the value \( m_B \), since the coordinates of point \( S_1 \) are determined directly by the total station from the reflector, for indirect determination of the basis length.

\[
m_{z1} = \sqrt{L^2 \cos^2 \delta \frac{m_y^2}{f^2} + m_y^2 \sin^2 \delta + 2m_y^2} \ , \ m
\]  

where \( m_{\delta} \) – root-mean-square error in of measuring the vertical angle \( \delta \) (the angle \( \delta \) is taken close to 0 °, since the measurements are made on the berm of the ledge and the instrument horizon is close
to the reflector horizon), for the total station it is taken equal to the angular accuracy of the 5 ° total station;

\[ m_V = \text{root-mean-square error of measuring the height of the tool is taken to be 1 mm.} \]

When establishing the type of dependence of the error of determining coordinates \( m_{X,G}, m_{Y,G}, m_{Z,G} \) on the exterior parameters of the cameras (projection centers) - B, L, using equations (3, 4, 5), it must be taken into account that these formulas are used in phototheodolite survey, and require correction making allowance for the current level of development of digital photogrammetry. During phototheodolite survey, positioning occurs at one or more points M (figure 1), connecting the pictures. Modern photogrammetric software for orienting images identifies and uses many tie points, the number of which can be more than a thousand (per one image). When assessing the accuracy of the coordinates determining of the points of the three-dimensional model, when surveying the proposed method, this fact suggests that the influence of the quantities \( X_1, Y_1, Z_1 \) in formulas (3, 4, 5) is minimal, therefore, take their values equal to 1.

Based on the analysis of the above equations (1, 2, 3, 4, 5), the main factors that allow us to describe the process of occurrence of errors when surveying the proposed methodology are: the distance \( B_i \), between the projection centers (points of photo images \( S_i \)), the distance from the total station to the camera L. The residuals \( \Delta X, \Delta Y, \Delta Z \) take part in the determination of the \( B \) and \( L \) distances. An increase in \( \Delta X, \Delta Y, \Delta Z \) leads to a distortion of the basis length \( B \), orientation elements, \( \alpha, \omega, \chi, \psi \), increases the errors in determining geodetic coordinates \( m_{X,G}, m_{Y,G}, m_{Z,G} \) and reduces the accuracy of determining coordinates points of the resulting three-dimensional model.

The results of the error analysis of determining geodetic coordinates with the proposed method are given in the graphs in figure 3 that describe the dependencies (equations 8-12)

**Figure 3.** The dependence of the errors in determining the coordinates of a point of a three-dimensional model on the photogrammetric parameters (base between photo station and distance between camera and total station)
\[
m_{x,g} = \frac{1.050 \cdot 10^3 + 0.474 \cdot L^{1244}}{1.024 \cdot 10^3 + L^{1244}}, r = 0.999
\]
(8)

\[
m_{y,g} = \frac{2.328 \cdot 10^3 + 0.741 \cdot L^{1244}}{1.252 \cdot 10^4 + L^{1244}}, r = 0.999
\]
(9)

\[
m_{z,g} = \frac{1}{7.880 - 6.219 \cdot 10^{-3} + 2.472 \cdot 10^{-6} \cdot L^2}, r = 0.999
\]
(10)

\[
m_{x,g} = m_{z,g} = \frac{1}{0.112 + 7.588 \cdot 1 \cdot B^{3426}}, r = 0.999
\]
(11)

\[
m_{y,g} = \frac{1.17 + 7.869 \cdot 1 \cdot B}{1 - 1.573 \cdot 1 \cdot B - 1.428 \cdot 1 \cdot B^2}, r = 0.999
\]
(12)

3. Results and discussions

In the course of practical implementation, an experimental quarry slope survey was carried out using the proposed photogrammetric methodology and a control survey using an electronic total station Nikon NPL-352. Marks fixing points were placed on the slope. Comparison of the coordinates of these points obtained by two independent methods of surveying slopes will allow to evaluate the proposed methodology and confirm the dependence of the development of errors \(m_{x,g}, m_{y,g}, m_{z,g}\) established in the study from the distance between the total station and the camera \(L\), terrestrial baseline \(B\) between neighboring images when photographing the slope.

In practice 4 groups of images were formed for independent further processing of these groups and determination of the coordinates of 4 characters from 4 independent models. figure 4 shows an example of the slopes of the ledges made during the study.

![Figure 4. Sample of image](image)

Pictures were processed in photogrammetric software Agisoft PhotoScan using the coordinates of the positions of the optical centers of the camera determined by the polar method using an electronic total station. Source coordinates of the positions of the optical centers of the camera alignment errors during reference of images are displayed in the figures 5, 6, 7.
**Figure 5.** Source coordinates of the optical centers of the camera obtained by Nikon NPL-352

**Figure 6.** Errors during alignment of images in Agisoft PhotoScan

**Figure 7.** Estimated by Agisoft PhotoScan coordinates of the optical centers of the camera

Fragments of the obtained digital three-dimensional models tuned according to the photogrammetry data are shown in figure 8.
Figure 8. Fragments of a three-dimensional model

In figure 8, the model is presented in various display options: a - surface, b - horizontal contours with step 0.1 m.

Comparison of the obtained coordinates of the signs on the slope by two measurement methods are given in table 1.

Table 1. Photogrammetric slope survey results

| Mark | Control coordinates obtained by Nikon NPL-352 [m] | Coordinates obtained by the proposed method [m] | Actual deviations [m] |
|------|---------------------------------------------|-----------------------------------------------|----------------------|
|      | X    | Y    | Z    | X    | Y    | Z    | x'   | y'   | z'   |
| 1    | 0.129| 7.324| 11.093| 0.025| 7.179| 10.996| 0.104| 0.145| 0.097|
| 2    | -1.070| 5.969| 10.021| -1.132| 5.873| 9.982| 0.062| 0.096| 0.039|
| 3    | -0.172| 5.818| 10.127| -0.247| 5.710| 10.083| 0.075| 0.108| 0.044|
| 4    | 0.183| 6.390| 10.56 | 0.097| 6.261| 10.499| 0.086| 0.129| 0.061|

The accuracy of the obtained coordinates is estimated using the formulas (3, 4, 5) based on the actual parameters L and B (figure 4), is performed in table 2. Table 2 also compares the actual deviations of the coordinates from table 1 with the theoretical values calculated by the equations (3, 4, 5), to establish the reliability of the method for estimating errors.

Table 2. Comparison of accuracy assessment results

| Mark | Parameters of surveying | Theoretical accuracy | Actual deviations | Difference in accuracy estimates |
|------|-------------------------|----------------------|-------------------|----------------------------------|
|      | B, m | L, m | $m_{X,G}$, [m] | $m_{Y,G}$, [m] | $m_{Z,G}$, [m] | $x'$, [m] | $y'$, [m] | $z'$, [m] | $m_{X,G}$, [m] | $m_{Y,G}$, [m] | $m_{Z,G}$, [m] |
| 1    | 3.448| 6.939| 0.105 | 0.250 | 0.130 | 0.104 | 0.145 | 0.097 | 0.001 | 0.105 | 0.033 |
| 2    | 3.773| 5.015| 0.105 | 0.232 | 0.129 | 0.062 | 0.096 | 0.039 | 0.043 | 0.136 | 0.090 |
| 3    | 4.055| 4.809| 0.104 | 0.219 | 0.129 | 0.075 | 0.108 | 0.044 | 0.029 | 0.111 | 0.085 |
| 4    | 3.904| 5.884| 0.105 | 0.226 | 0.129 | 0.086 | 0.129 | 0.061 | 0.019 | 0.097 | 0.068 |
Based on the data in table 2, the difference in the estimates of the accuracy of the coordinates are positive. Values of indicators $m_{X,G}$, $m_{Y,G}$, $m_{Z,G}$ more values of actual deviations $x'$, $y'$, $z'$. The areas described by the proposed indicators contain the true values of the coordinates of the points of the three-dimensional model, which means that the method for assessing the accuracy of measurements allows to conclude about the quality of the survey as a whole. Therefore, the applied estimation method and the proposed error indicators for determining the coordinates meet the reliability requirement.

The experimental surveys of the slopes of ledges using terrestrial photogrammetry, the analysis of the sources of errors when positioning the images with a total station, confirm that this method of surveying meets the established requirements for surveying operations in the extraction of solid minerals in terms of the accuracy of surveying in the quarry (0.4 m in planimetry for a scale of 1: 1000 and elevations of 0.2 m).

4. Conclusions

Based on the studies, the following results were obtained:

1. The method of measuring of the slopes of ledges in the framework of geomechanical monitoring is proposed. The method is based on the use of terrestrial photogrammetry and the measuring of the position of the camera by an electronic total station (only the coordinates of the external orientation of the images are measured, in the image space is not measuring any GCP). Specified accuracy has been reached - 0.4 in the planimetry and in the altitude - 0.2 m (for a scale of map 1: 1000).

2. An analysis of the accuracy of measurements is performed. The main patterns and sources of errors were defined. Criteria for assessing accuracy and methods are proposed for calculating them. The dependency graphs are presented describing the influence of the parameters of the measurement on the accuracy of the work.

3. The results of the photogrammetric determination of the spatial position of the control points are compared with the direct geodetic measurement by the total station. During the study, in practice, comparable results were established with an geodetic measurement method, which allows confirming the conformity of the measurement results to the required accuracy. The error in determining the coordinates of the points of the three-dimensional model by the proposed survey method (0.4 m and 0.2 m) are acceptable.

Based on the foregoing, the proposed methodology is applicable for measuring of slopes on benches for the purpose of geomechanical monitoring and quality control of setting benches in their in newly designed position.

4. The result of processing the measuring data is the coordinates of the slope points and its elements, a three-dimensional model, a point cloud, wireframe model, a height map, topographic surfaces in horizontal lines, volume and area data.

References

[1] S.G. Ozhigin, F.K. Nizametdinov, S.B. Ozhigina, and D.S. Ozhigin. Innovative methods for monitoring the state of stability of rocks and the ground surface. IntExpo Geo-Siberia, B1–1, 135-140, 2014 (in Russian).

[2] O.D. Zheltisheva. Application of technology of laser scanning for monitoring of deformations of buildings and constructions. Proc. of conf. Geomechanics in mining IOM UrO RAOS, Yekaterinburg 2011, 189–194, 2012 (in Russian).

[3] D.S. Ozhigin. Ensuring stability of slopes of open pit wall in a zone of transportless overburden.
removing. Proceedings of university KarSTU, 68-72, 2017 (in Russian).

[4] E.N. Tokunzhin, S.A. Rostov, S.G. Ozhigin, S.B. Ozhigina. Geomechanical monitoring using modern measurement methods Proc. of conf: Innovative technologies in surveying, mine surveying and geotechnics KarSTU, Karaganda 2017, 103-109, 2017 (in Russian).

[5] G.J. Dick, E. Eberhardt, A. Cabrejo-Liévano, G.D. Stead, N.D. Rose. Development of an early-warning time-of-failure analysis methodology for open-pit mine slopes utilizing ground-based slope stability radar monitoring data. Canadian Geotechnical Journal. 52(4), 515-529, 2015.

[6] F. Sanchez, B. Royo, and F. Meloni. InSAR ground motion monitoring for mining areas. Proc. of conf: Innovative technologies in surveying, mine surveying and geotechnics KarSTU, Karaganda 2017, 15-21, 2017.

[7] A.L. Avtuyshenkov, V.M. Ivanov. Computer tenologies for converting two-dimensional objects into a three-dimensional scene. Scientific and technical statements of St. Petersburg State Polytechnic University. Computer science. Telecommunications. Control, 5(229), 7-17, 2015 (in Russian).

[8] S.Y. Choi, J.M. Kang, D.S. Shin. A comparison of accuracies of the RPC models : homo- and hetero type stereo pairs of GeoEye and WorldView images. ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci., I-4, 65-69, 2012. doi: 10.5194/isprsannals-I-4-65-2012.

[9] N.E. Zharova, A.G. Chibunichev. Analysis of the accuracy of determining the coordinates of terrain points when using "random" stereo pairs of satellite images. Geodesy and aerophotosurveying. MIIGAiK, B61-5, 79-86, 2017 (in Russian).

[10] M. Daakir, M. Pierrot-Deseilligny, P. Bossier, F. Pichard, C. Thom. UAV onboard photogrammetry and GPS positioning for earthworks. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. XL-3/W3. 293-298, 2015.

[11] M. Blaha, H. Eisenbeiss, D. Grimm, P. Limpach. Direct georeferencing of UAVs. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XXXVIII-1/C22, 131-136, 2011.

[12] R. Teeuw, et. al., Field Techniques: GIS, GPS and Remote Sensing. London: Geography Outdoors Royal Geographical Society (with IBG), 368 p., 2005.

[13] Y.B. Blohinov, M.S. Verkeenko, S.V. Skryabin, E.E. Andrienko. Automatically orient an unordered set of overlapping pictures. Geodesy and aerophotosurveying. MIIGAiK, B61-5, 91-98, 2017 (in Russian).

[14] V.N. Popov, et. al.. Surveying work in quarries and mines. Moscow: Nedra, 424 p., 1989 (in Russian).

[15] H. Staňková, V. Šafář, R. Dandoš. A priori determining of the accuracy of mineral resources volume determination. Gospodarka Surowcami Mineralnymi – Mineral Resources Management, 34(3), 5-21. 2018. DOI: 10.24425/122577. ISSN 2299-2324. Direct to: http://hdl.handle.net/10084/132626

[16] Committee for State Control of Emergencies and Industrial Safety of the Republic of Kazakhstan. Methodical recommendations for surveying in the extraction of solid minerals. Astana: KGKPB, 509 p., 2009 (in Russian).

[17] Federal inspectorate for mining and industry of Russia. Protection of subsurface resources and geological-surveying control. Instruction for surveying works. Moscow: FGUP, 117p., 2004 (in Russian).

[18] S.G. Ozhigin, F.K. Nizameddinov, S.B. Ozhgina. Mine surveying assurance of stability of the rock mass of open pit walls. System for monitoring the state of stability of open pit slopes]. Saarbruecken: LAP LAMBERT Academic Publishing, 306 p., 2015 (in Russian).