UDC 622.1:622.83+622.35

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EVALUATION OF ACCURACY OF PHOTOGRAMMETRIC METHODS AND LASER SCANNING FOR MEASURING OF PARAMETERS OF CRACKS NATURAL SEPARATENESS

The modern approach of evaluation of errors of surface digital photogrammetric survey is considered. The possibilities of taking into account the impact of error of the system of treatment of digital representation and parameters of digital matrix on exactness of determination of actual coordinates of points are considered. The methods of quality assessment identifying cracks on the results of photogrammetric surveys and the estimation accuracy of the length and area of cracks are offered. The calculations of theoretical step of scanning for different categories of cracks using laser scanners VZ-400, VZ-1000, VZ-4000 of the RIEGL Company are executed. The order of determination of limits of area of laser scanning is reasonably depending on the parameters of cracks and technical descriptions of the laser scanner. According to the results of the calculations the method of determining the optimal parameters of laser scanning for different types of cracks is proved. Reasonable rational directions of the use of digital surface photogrammetric surveys and laser scanning in the study of multilevel fractured deposits of minerals are substantiated.

Keywords: *quarries; decorative stone blocks; photogrammetry; non-metric digital cameras; 3D laser scanner; cracks; surface digital photogrammetric survey.*

Introduction and problem statement. At the estimation of fracture of building materials, a basic problem is a relatively small amount of measuring of parameters of cracks caused the large implementation of these works. The ways found to increase productivity and efficiency measurements of fracture showed that the most effective photogrammetric methods should be studied. In addition, from the point of view of economic component of the measurement process, the non-metric digital cameras are the most promising application to be considered, the use of which will not only measure the linear dimensions of existing defects, but also identify areas change basic settings.

One of the main characteristics of the fracture is the average width of the cracks on an area. According to the geometric classification, cracks by their width are divided into the following categories:
- capillaries < 0,0001 m;
- narrow cracks 0,0001–0,001 m;
- middle cracks 0,001–0,01 m;
- wide fissures 0,01–0,1 m;
- cracks 0,1–1 m;
- zones of crushing of breaks > 1 m.

Other features include the length of cracks and area of proposed determination to carry through modern laser scanners and non-metric digital cameras.

The aim of the article is determination the optimal parameters of laser scanning and surface digital photogrammetric surveys with the estimation of their accuracy for different types of cracks.

Analysis of researches and publications. A large number of scientific papers are devoted to the application of non-metric cameras and their research. Determination of length, width and shape of some cracks opening through the use of digital camera (or camcorder when necessary high frequency data collection) and supporting coordination aluminum frame (16 points), which establishes a system of coordinates of the object, and a pair of support bars (3 point seat on a regular basis on both sides of the crack) determine the strain considered in the work [1]. The measurement process is carried out in a fully automated mode, the accuracy of the proposed method determined by the experimental results for various non-metric cameras, estimated at ± 5-20 micron accuracy and meets the most mechanical devices for measuring strain.

In work [2] the use of digital photographic equipment to capture of sides quarries, computer technology data on fractures and their interpretation for corrected parameters used in modeling sustainability sides quarries is shown. Use of photogrammetric techniques to study fracturing parameters and their development under the appl ess fractures, including establishing correlations betw d on the single element design is described in [3]. Schemes deformation measurements and optical inhomogeneity in white light as much as 100 mm with an accuracy of 0,3 mm with artificial speckle-structures are implemented in work [4]. This paper focuses on the fact that the use of artificial speckle-structures can significantly increase the number of control points on the image

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and increase productivity measurement. The downside to be considered that the implementation of the approach proposed artificial speckle patterns were printed by printer on plain paper without deformation paper and fidelity base image while options speckle patterns were determined by analyzing its digital model.

In work [5] a question in relation to influence the errors of calibration of survey cameras on the accuracy of determination of coordinates of points of objects at a surface shortbasis photogrammetric survey is considered. These calculations were executed for non-metric digital cameras Canon EOS 350D, Canon EOS 450D and Canon EOS 5D Mark II. The expected accuracy of the coordinates of points at application of digital photogrammetry according to the results researches of Hlotov [6] can be determined from expression:

$$
\begin{aligned}
m_{X_\Phi} &= \frac{Y_\Phi}{f} x_з \cdot \left[\left(\frac{m_{x_з}}{x_з}\right)^2 + \left(\frac{m_p}{p}\right)^2 + \left(\frac{x_з}{pf} m_{\Delta\alpha}\right)^2 + \left(\frac{x_з z_з}{fp} m_{\Delta\omega}\right)^2 + \left(\frac{z_з}{p} m_{\Delta x}\right)^2 + \left(\frac{x_з}{f} m_v\right)^2 \right]^{1/2} \\
m_{Y_\Phi} &= Y_\Phi \cdot \left[\left(\frac{m_p}{p}\right)^2 + \left(\frac{x_з}{pf} m_{\Delta\alpha}\right)^2 + \left(\frac{x_з z_з}{fp} m_{\Delta\omega}\right)^2 + \left(\frac{z_з}{p} m_{\Delta x}\right)^2 + \left(\frac{x_з}{f} m_v\right)^2 \right]^{1/2} \\
m_{z_з} &= \frac{Y_\Phi}{f} z_з \cdot \left[\left(\frac{m_{z_з}}{z_з}\right)^2 + \left(\frac{m_p}{p}\right)^2 + \left(\frac{x_з}{pf} m_{\Delta\alpha}\right)^2 + \left(\frac{x_з z_з}{fp} m_{\Delta\omega}\right)^2 + \left(\frac{z_з}{p} m_{\Delta x}\right)^2 + \left(\frac{x_з}{f} m_v\right)^2 \right]^{1/2}
\end{aligned}
\tag{1}
$$

where Y_Φ is the distance to the object of output;

f is the focal distance;

$x_з, z_з$ is the maximal coordinates of the image;

p is the middle value of parallax in stereo;

m_p is the mean square error of parallax in stereo;

$m_{\Delta\alpha}$, $m_{\Delta\omega}$, $m_{\Delta\chi}$ is the mean square error of determining the angular elements of external orientation;

m_v is the mean square error inclination basis.

In the above-mentioned formula the impact of errors of the system of digital image processing and parameters of digital matrix on the accuracy of determination of actual coordinates of points is not considered. This defect is aught removed in labour [5] as a result of what the following formula was got:

$$
\begin{aligned}
m_X &= mx_1 \cdot \left[\left(\frac{m_{x_1}}{x_1}\right)^2 + \left(\frac{Y_\Phi \cdot m_p}{f \cdot B}\right)^2 + \left(\frac{Y_\Phi \cdot x_1}{f^2 \cdot B} m_{\Delta\alpha}\right)^2 + \left(\frac{Y_\Phi \cdot x_1 \cdot z_1}{f^2 \cdot B} m_{\Delta\omega}\right)^2 + \left(\frac{Y_\Phi \cdot z_1}{f \cdot B} m_{\Delta\chi}\right)^2 + \left(\frac{x_1}{f} m_v\right)^2 \right]^{1/2}, \\
m_Y &= mf \cdot \left[\left(\frac{Y_\Phi \cdot m_p}{f \cdot B}\right)^2 + \left(\frac{Y_\Phi \cdot x_1}{f^2 \cdot B} m_{\Delta\alpha}\right)^2 + \left(\frac{Y_\Phi \cdot x_1 \cdot z_1}{f^2 \cdot B} m_{\Delta\omega}\right)^2 + \left(\frac{Y_\Phi \cdot z_1}{f \cdot B} m_{\Delta\chi}\right)^2 + \left(\frac{x_1}{f} m_v\right)^2 \right]^{1/2}, \\
m_Z &= mz_1 \cdot \left[\left(\frac{m_{z_1}}{z_1}\right)^2 + \left(\frac{Y_\Phi \cdot m_p}{f \cdot B}\right)^2 + \left(\frac{Y_\Phi \cdot x_1}{f^2 \cdot B} m_{\Delta\alpha}\right)^2 + \left(\frac{Y_\Phi \cdot x_1 \cdot z_1}{f^2 \cdot B} m_{\Delta\omega}\right)^2 + \left(\frac{Y_\Phi \cdot z_1}{f \cdot B} m_{\Delta\chi}\right)^2 + \left(\frac{x_1}{f} m_v\right)^2 \right]^{1/2},
\end{aligned}
\tag{2}
$$

where m is the denominator scale of survey;

x_1, z_1 is an abscissa and applicants of coordinates of point point on CCD digital camera;

B is the basis of survey;

m_p, m_{x_1}, m_{z_1} is the mean square error of measurement of coordinates of the image on the DPS "Delta-2".

The use of digital methods of surface survey of quarries is investigated in works [8-11].

Basic material report of the article. With the aim of estimation of quality of the identification of cracks and efficiency of work above-mentioned algorithms of treatment for digital image it is necessary to execute comparison of standard parameters cracks with those obtained in program "Detector cracks".

The main parameters of estimation of quality of the identification of cracks accept their length L_{mp} and area S_{mp}. They are determined by the following formulas:

$$
\begin{aligned}
&L_{mp} = \sqrt{(X_L - X_{0L})^2 + (Y_L - Y_{0L})^2 + (Z_L - Z_{0L})^2}, \\
&S_{mp} = L_{mp} \cdot B_{mp} = \sqrt{(X_L - X_{0L})^2 + (Y_L - Y_{0L})^2 + (Z_L - Z_{0L})^2} \times \\
&\times \sqrt{(X_L - X_{0B})^2 + (Y_L - Y_{0B})^2 + (Z_L - Z_{0B})^2},
\end{aligned}
\tag{3}
$$

where X_L, Y_L, Z_L, X_{0L}, Y_{0L}, Z_{0L}, X_{0B}, Y_{0B}, Z_{0B} is spatial coordinates of points of cracks;

B_{mp} is a width of opening of cracks.

Mean-square error of length and area cracks determine by the following general formulas:

$$d^2 f(X,Y,Z)=\left(\frac{\partial f(X,Y,Z)}{\partial X}\right)^2\cdot dX^2+\left(\frac{\partial f(X,Y,Z)}{\partial Y}\right)^2\cdot dY^2+\left(\frac{\partial f(X,Y,Z)}{\partial Z}\right)^2\cdot dZ^2. \qquad (4)$$

Given that $\Delta X = X_L - X_{L0}$, $\Delta Y = Y_L - Y_{L0}$, $\Delta Z = Z_L - Z_{L0}$ and errors $m_X = m_{Xo}$, $m_Y = m_{Yo}$, $m_Y = m_{Yo}$, substitute formula (3) in (4) and get:

$$\begin{aligned} m_{L_{mp}}^2 &= 2\cdot\left(\frac{(\Delta X^2+\Delta Y^2+\Delta Z^2)'}{2\sqrt{\Delta X^2+\Delta Y^2+\Delta Z^2}}\right)^2 m_X^2+2\cdot\left(\frac{(\Delta X^2+\Delta Y^2+\Delta Z^2)'}{2\sqrt{\Delta X^2+\Delta Y^2+\Delta Z^2}}\right)^2 m_Y^2+2\cdot\left(\frac{(\Delta X^2+\Delta Y^2+\Delta Z^2)'}{2\sqrt{\Delta X^2+\Delta Y^2+\Delta Z^2}}\right)^2 m_Z^2 = \\ &= 2\cdot\left(\frac{\Delta X}{\sqrt{\Delta X^2+\Delta Y^2+\Delta Z^2}}\right)^2 m_X^2+2\cdot\left(\frac{\Delta Y^2}{\sqrt{\Delta X^2+\Delta Y^2+\Delta Z^2}}\right)^2 m_Y^2+2\cdot\left(\frac{\Delta Z^2}{\sqrt{\Delta X^2+\Delta Y^2+\Delta Z^2}}\right)^2 m_Z^2 = \\ &= \frac{2\Delta X^2}{\Delta X^2+\Delta Y^2+\Delta Z^2}m_X^2+\frac{2\Delta Y^2}{\Delta X^2+\Delta Y^2+\Delta Z^2}m_Y^2+\frac{2\Delta Z^2}{\Delta X^2+\Delta Y^2+\Delta Z^2}m_Z^2 = \\ &= 2\cdot\frac{\Delta X^2 m_X^2+\Delta Y^2 m_Y^2+\Delta Z^2 m_Z^2}{\Delta X^2+\Delta Y^2+\Delta Z^2}. \end{aligned} \qquad (5)$$

While considering the expression (5) the accuracy of determination of the crack length is:

$$\begin{aligned} m_{L_{mp}}^2 &= \frac{2}{\Delta X^2+\Delta Y^2+\Delta Z^2}\cdot\left[\Delta X^2\cdot mx_1\cdot\left[\left(\frac{m_{x_1}}{x_1}\right)^2+\left(\frac{Y_\Phi\cdot m_p}{f\cdot B}\right)^2+\left(\frac{Y_\Phi\cdot x_1}{f^2\cdot B}m_{\Delta\alpha}\right)^2+\left(\frac{Y_\Phi\cdot x_1\cdot z_1}{f^2\cdot B}m_{\Delta\omega}\right)^2\oplus \right.\right.\\ &\left.\left.\oplus\left(\frac{Y_\Phi\cdot z_1}{f\cdot B}m_{\Delta\chi}\right)^2+\left(\frac{x_1}{f}m_\nu\right)^2\right]\right]\oplus \\ &\oplus\Delta Y^2\cdot mf\cdot\left[\left(\frac{Y_\Phi\cdot m_p}{f\cdot B}\right)^2+\left(\frac{Y_\Phi\cdot x_1}{f^2\cdot B}m_{\Delta\alpha}\right)^2+\left(\frac{Y_\Phi\cdot x_1\cdot z_1}{f^2\cdot B}m_{\Delta\omega}\right)^2+\left(\frac{Y_\Phi\cdot z_1}{f\cdot B}m_{\Delta\chi}\right)^2+\left(\frac{x_1}{f}m_\nu\right)^2\right]\oplus \\ &\oplus\Delta Z^2\cdot mz_1\cdot\left[\left(\frac{m_{z_1}}{z_1}\right)^2+\left(\frac{Y_\Phi\cdot m_p}{f\cdot B}\right)^2+\left(\frac{Y_\Phi\cdot x_1}{f^2\cdot B}m_{\Delta\alpha}\right)^2+\left(\frac{Y_\Phi\cdot x_1\cdot z_1}{f^2\cdot B}m_{\Delta\omega}\right)^2+\left(\frac{Y_\Phi\cdot z_1}{f\cdot B}m_{\Delta\chi}\right)^2+\left(\frac{x_1}{f}m_\nu\right)^2\right]. \end{aligned} \qquad (6)$$

In view of (3) the accuracy of determination of area of crack can be described by the following expression:

$$\begin{aligned} m_{S_{mp}}^2 &= L_{mp}^2\cdot m_{B_{mp}}^2+B_{mp}^2\cdot m_{L_{mp}}^2=(\Delta X^2+\Delta Y^2+\Delta Z^2)\cdot m_{B_{mp}}^2+(\Delta X^2+\Delta Y^2+\Delta Z^2)\cdot m_{L_{mp}}^2 = \\ &= 4\cdot(\Delta X^2 m_X^2+\Delta Y^2 m_Y^2+\Delta Z^2 m_Z^2). \end{aligned} \qquad (7)$$

Today the method of surface laser scanning is widely used in mine surveying to calculate the mines volume and warehouses, creating digital models of open-pits and underground workings for the purpose of monitoring, support drilling and blasting, etc. This paper considers the feasibility of using this method on block stone quarries.

A formula established and confirmed practically by scientists [7] is used for determination of cracks, which can be measured by surface laser scanner:

$$\Delta\varphi=\frac{d}{\sqrt{2}\cdot S}\cdot\frac{180}{\pi}, \qquad (8)$$

where d is the minimum size of the object that should be displayed on the scan;

S is the distance from the scanner to the object of survey.

The minimum size of the object taken in turn limiting the size categories cracks (considered only capillaries, narrow, medium and wide cracks), the distance from the scanner to the object of survey determines the minimum distance scanning set for each type of surface laser scanner. This paper used Technical descriptions of laser scanner VZ-400 (minimum distance scanning 1.5m), VZ-1000 (2.5 m), VZ-4000 (5 m) of the company RIEGL (laser scanners of the firm is defined innovative 3D technology and terrestrial laser scanners VZ-400, VZ-1000 and VZ-4000 behave to those series, that this firm produces for today) were used in this work. The results of calculations are shown in Table 1.

Table 1

Results of calculations of theoretical scanning step

Type and width of cracks, m		Minimum distance of scanning, m	Theoretical step of scanning, °	Minimum step of scanning device, °
Capillaries	0,0001	1,5 (VZ-400)	0,0027	0,0024
	0,0001	2,5 (VZ-1000)	0,0016	0,0024
	0,0001	5 (VZ-4000)	0,001	0,002
Narrow cracks	0,001	1,5 (VZ-400)	0,0270	0,0024

	0,001	2,5 (VZ-1000)	0,0162	0,0024
	0,001	5 (VZ-4000)	0,008	0,002
Medium cracks	0,01	1,5 (VZ-400)	0,2701	0,0024
	0,01	2,5 (VZ-1000)	0,1621	0,0024
	0,01	5 (VZ-4000)	0,081	0,002

The table shows that the capillaries cannot be measured using these types of laser scanners, but if you perform measurements with VZ-400, then narrow cracks can be singled out from the cloud of points. VZ-1000 and VZ-4000 except VZ-400 are also suitable for measuring all other types of cracks.

More detailed consideration shows that the smallest types of cracks that can be measured are narrow cracks. Accordingly surface laser scanner VZ-400 will be used in further calculations technical descriptions.

While converting a formula (8) to the form:

$$S_{\max} = \frac{d}{\sqrt{2} \cdot \Delta\varphi_{\min}} \cdot \frac{180}{\pi}, \qquad (9)$$

it is possible to define maximal distance of setting of device from the object of survey. Thus, the measured laser scanner VZ-400 ($\Delta\varphi_{\min} = 0{,}0024^\circ$) narrow cracks (d = 0,0001 m), the numerical value of this distance will be:

$$S_{\max} = \frac{0{,}0001}{\sqrt{2} \cdot 0{,}0024} \cdot \frac{180}{\pi} \approx 1{,}7 \text{ m}. \qquad (10)$$

For determination of limits of implementation of survey when the above conditions (Fig. 1) perform the following calculation.

From Fig. 1 it is possible to get the following analytical dependence:

$$\alpha = 2 \cdot \arccos\frac{S_{\min}}{S_{\max}} = 2 \cdot \arccos\frac{1{,}5}{1{,}7} \approx 56^\circ, \qquad (11)$$
$$l = 2 \cdot \sqrt{S_{\max}^2 - S_{\min}^2} = 2 \cdot \sqrt{1{,}7^2 - 1{,}5^2} = 0{,}8 \text{ m}.$$

For measuring the area of array, which corresponds $\alpha = 56^\circ$ with step scanning $d = 0{,}0024^\circ$ and scanning speed $\upsilon_{ск} = 80$ lines / sec (for surface laser scanner VZ-400 scanning speed from 3 to 120 lines / sec) it is necessary to spend:

$$t = \frac{\alpha}{d \cdot \upsilon_{ск}} = \frac{56}{0{,}0024 \cdot 80} \approx 292 \text{ sec} = 4 \text{ min } 52 \text{ sec}. \qquad (12)$$

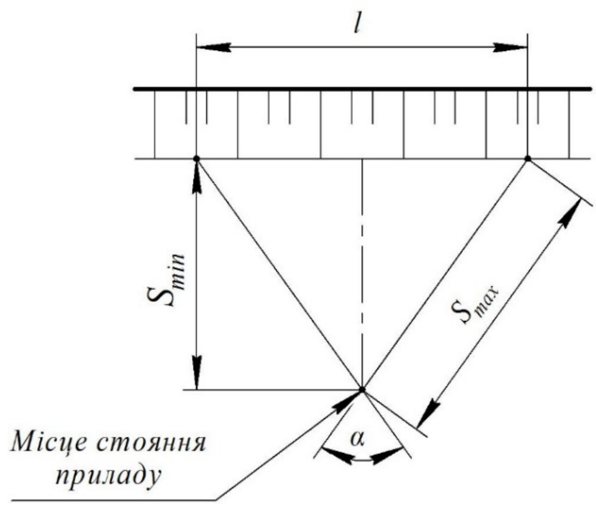

Fig. 1. Determination of limits of implementation of survey

Conclusions. A method of surface laser scanning is a perspective method for measuring the quarries stone block. Using a laser scanner only on one quarry through its high price is unprofitable, that is why at the use of one device for the decision of mountain tasks on a few careers is rational. Previous calculations proves that it is impossible to define spatial position of a capillary in an array, but if it is necessary the elements of bedding of these cracks can be defined by other accessible ones under the conditions method, and then with the received results to complement the spatial model created by the method of laser scanning. But at all these defects this method allows to create a spatial model of the investigated area or all quarry at relatively short time and use it quickly and productively to decide various mining tasks.

Prospects of further research. Based on the above developed methods, the future plans are to perform practical research directly on quarries of blocks stone. It is planned to determine the reliability of the practical value and investigate possibility of automation developed techniques

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Стаття надійшла до редакції 26.05.2016