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ORIGINAL PAPER

THE POSSIBILITY OF USING CLOSE-RANGE MONO-PHOTOGRAMMETRY IN MEASURING RELATIVE DISPLACEMENTS OF ROCK BLOCKS

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ABSTRACT
The paper presents a method for measuring relative displacements of rock blocks on the basis of recorded images of prototype plate targets measurement. The developed measuring targets, after deposition on the surveyed object (for example rock blocks) act as control points, which represent the behavior of the object over time. Two types of targets ware constructed: passive (appropriately chosen figure) and active (respectively arranged fiber targets). The paper presents preliminary results of work in the laboratory using a calibrated semi-metric camera (Canon D5 Mark II - SLR camera with a CMOS 21 million pixels sensor), two passive targets, geodetic engineering tripod, micrometric simulator of shifts and Leica TC1800 total station.
During the experimental work one of the targets was set on a tripod, and the other placed on the total station telescope set on the observation pillar. While taking a series of images the first target was fixed, while the other was moved and rotated. The displacements were made with a micrometric table in two mutually perpendicular directions XY in the horizontal plane, and by simulated rotation of the horizontal wheel and vertical wheel of the total station (rotation of the instrument by the adjusting screws). Using the principles of close-range mono-photogrammetry from automatic measurement of the recorded images of both plate targets, the values of displacements and rotations were compared with the references.

KEYWORDS: close-range mono-photogrammetry, deformation measurement, plate target, rock block

1. INTRODUCTION

In the environment one may notice both natural and man-made changes. These changes are, inter alia, in the form of rock cracks, landslides and mining damages. In order to ensure safety of people and their property they need to be controlled.

The changes are monitored in the natural environment using specialist equipment that performs relative and absolute measurements (Borre et al., 2003; Cheung, 1996; Kavvadas, 2003; Pelzer, 1988). The selection of measuring method depends on the magnitude and character of changes. The scope and periodicity of measurements, the required measurement accuracy as well as frequency of measurements need to be considered when selecting the technology of measurements. Geodetic measurements may be divided into three accuracy classes. The first class comprises GPS satellite observation and precise levelling (Kontny, 2003), where the precision of displacement measurements averages ±0,5÷10 mm. The second class includes measurements carried out using electronic tachymeters which enable to increase the accuracy of displacement measurements to ±0.5÷2 mm (Kapłon, 2005). The third and most precise class (the accuracy of displacement measurements is ±0.01÷0.1 mm) relies on the relative measurements performed using clinometers, extensometers and inclinometers (Bryś and Ćmielewski, 2009; Bryś et al., 2011; Ćmielewski, 2007; Ćmielewski et al., 2011; Ćmielewski et al., 2012; Jamroz et al., 2006; Kaczorowski and Wojewoda, 2011).

The analysis of research works carried out on various geological objects (Cacoń et al., 2010) indicates that systems that have been developed and are operating these objects are multi-segment control systems (Kapłon, 2005). They facilitate registration of relative and absolute observations. The angular and linear measurements taken using total stations support the inclusion of relative observations (crack gauge, strain gauge) to the reference frame where absolute measurements are carried out.

The development of the optoelectronic technique and measuring capabilities of modern cameras encouraged the authors of this paper to design a set of devices that can be employed to determine relative and absolute displacements on geological and engineering objects. The solution suggested is based on the photogrammetric method (Kraus, 2007). The designed measuring set was tested in the laboratory.

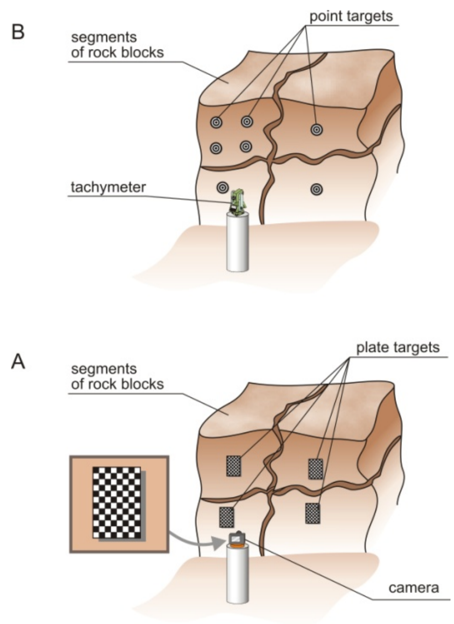


Fig. 1 The measurement of rock block displacements:
a). standard measurements;
b). measurements using the photogrammetric method

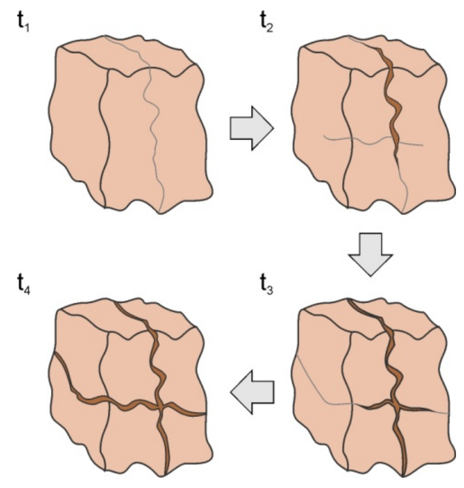


Fig. 2 Phases of the rock bloc behaviour in the time interval [t_1,t_4].

The article presents the measuring capabilities of the designed measuring kit and the results of its accuracy analyses.

2. THE CONCEPTION OF ROCK BLOCK DISPLACEMENTS BASED ON TERRESTRIAL MONO-PHOTOGRAMMETRY

The article discusses the prototype of a device that was designed and built in the Institute of Geodesy and Geoinformatics IGG (Wroclaw University of Environmental and Life Sciences) for the purpose of measuring relative and absolute displacements on geological and engineering objects.

The measuring kit may be used to gauge deformations and displacements caused by movements of rock masses, mining as well as hydrogeological, geotechnical and construction works. Figure 1 illustrates the idea of the elaborated method and the technique of measuring deformations with reference to standard methods of measurements which involve GPS, total station and relative measurements.

By the application of GPS and tachymetric techniques it is possible to determine the position of the station with respect to the reference frame. Then, the position of targets placed on rock blocks is determined through tachymetric observations. Figure 2 depicts possible phases of the change occurring on a single rock block in the time interval [t_1, t_4]. Shifts in the position of a single rock block are registered as changes of their respective angles (Fig. 3). In order to obtain complete information about the object behaviour, i.e. movements, rotations, changes in shape, it is necessary to stabilise the right number of targets and devices for relative measurements.

Figure 1a illustrates the determination of rock blocks displacements using three measuring techniques: the GPS technique, tachymetric measurements and relative measurements. The method elaborated by the IGG enables to replace tachymetric and relative measurements with terrestrial mono-photogrammetry. In this method instead of 4 point targets, a plate target was used with measuring points fixed to it. There are two types of plate targets: a passive plate target and an active plate target. The selection of the plate target to be used on the object depends on the type and the structure of the object. Plate targets may be installed permanently on the object or may be placed there temporarily only for the period of time when measurements are taken (Fig. 4).

The flat surface of the passive plate target includes N measuring points located in the corners of a black-white chessboard whose size is n_x by n_y squares, thus number of measuring points N is equal to $(n_x + 1) \cdot (n_y + 1)$. The size of a single square is l_x by l_y mm. The number of squares and their size depends on the type and the structure of the object and the measuring equipment used. When the active plate target is used there are M measuring points located on its surface which are signalled with optical fibres. The distance between points L_x and L_y depends on the type and structure of the object and measuring equipment used. Prior to the commencement of measurements, both plate targets and measuring equipment (CCD/CMOS camera) need to be calibrated in the laboratory. The calibration of plate targets may be carried out using a precise mono- or stereo-comparator which support positioning of the measuring points marked on the surface of a plate target with the accuracy of hundredth parts of a millimetre. Depending on the type and the structure of the object while recording images with camera the passive plate target may be illuminated with natural light (sun

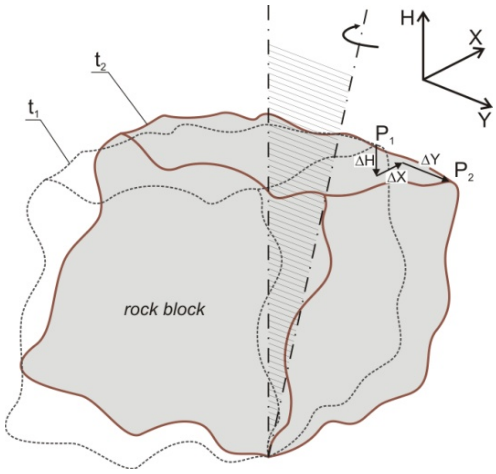


Fig. 3 The behaviour of a single rock block in the time interval $[t_1,t_2]$ in global coordinates XYH.

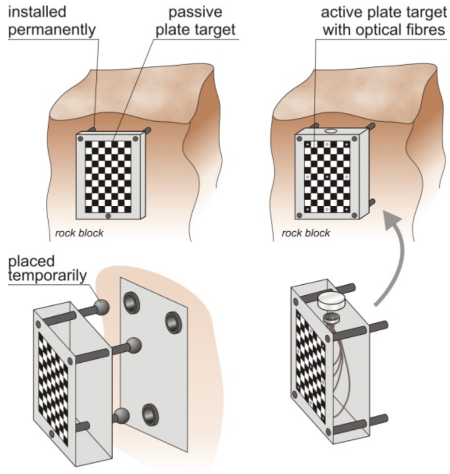


Fig. 4 Methods of installing plate targets on the object.

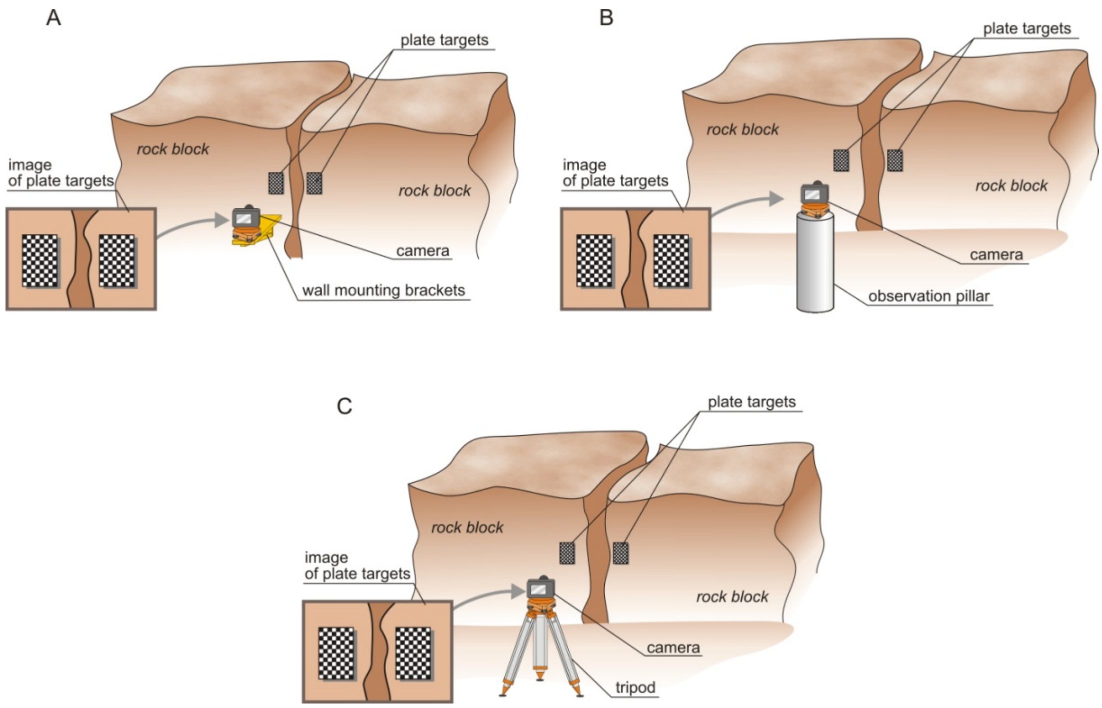


Fig. 5 Types of camera stations during observations
A. camera mounted on wall mounting brackets;
B. camera mounted on the observation pillar;
C. camera mounted on a surveying tripod.

light), artificial light (reflected-reflexive light) or transparent light (which goes through the transparent plate target) and the survey points of the active plate target may be lit with natural and artificial light.

To test the measuring equipment the authors used a passive plate target with 96 measuring points located in the corners of black and white chessboard whose size is 7 by 11 squares. The size of a single square is 10x10 mm.

CCD/CMOS camera may be set on the object in different ways depending on the type of displacements (relative or absolute) being observed (Fig. 5). The type of the object and the observation requirements determine whether to monitor the object continuously or periodically. The continuous monitoring typically involves a camera mounted on wall mounting brackets or on the observation pillar. The results of measurements, irrespective of the type of monitoring, may be carried to the central computation unit through a cable system or wirelessly.

It is a prerequisite to place plate targets on rock blocks in such a way they are in the field of view of

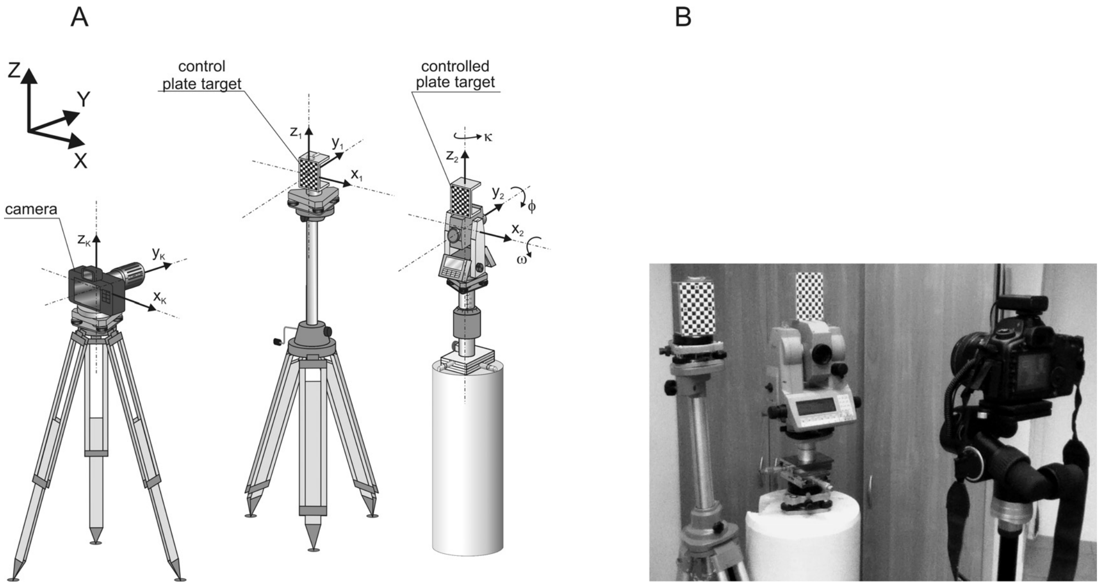


Fig. 6 Measuring equipment used in the research and experimental works:
A. diagram illustrating the arrangement of equipment in local coordinates XYZ;
B. instruments used in the experiments.

the camera set on the tripod. The photographing parameters (diaphragm and focal distance) which affect the depth of focus and the scale of the registered image need to be adjusted accordingly. The first method of mounting the camera is typically used when measuring the relative displacements. Before the measurements the wall mounting brackets are assembled to one of the rock blocks and at least one plate target is installed on the block to be controlled (Fig. 5a presents a control block and a controlled block). If there are two plate targets installed on the control block, the second target enables to check the stability of the wall mounting brackets and to keep the right orientation of the recorded images. If the position of the CCD/CMOS station is determined in the external reference frame using the selected method, then the displacements which were measured may be converted to the absolute values.

The second method of measurement requires stabilising the station of camera (observation pillar) beyond the impact of forces that cause displacements. Just like in the first method, this method needs to specify the position of the camera station in the external reference frame. This would enable to determine absolute displacements of plate targets representing the examined object. Otherwise, the identified displacements will be relative displacements.

The third option depends on mounting the camera on the surveying tripod during the measurements. The tripod is located over the point whose coordinates are established in the reference frame. In this case it is essential to install at least two plate targets on the researched object in order to maintain the required orientation of photographs.

There are two methods to set the camera correctly and to check the initial conditions of its orientation. When orienting the camera using the first method the camera is mounted on the wall mounted brackets or on the measuring pillar and connected to a selected remote target (out of range of the rock mass). Prior to the commencement of measurements, the selected method is used to determine the position of the camera station (Fig. 5). When only relative displacements are being determined (the second method of camera orientation), at least two plate targets are installed on rock blocks; one of them is used for camera orientation and to refer the measurement results to the other plate target(s).

3. EXPERIMENTAL WORKS – CALIBRATION AND SURVEY

Experimental works were done in the laboratory of the Institute of Geodesy and Geoinformatics of the Wroclaw University of Environmental and Life Sciences. For the purpose of research Canon EOS 5D Mark II semi-metric camera was used. This camera is a single-lens reflex camera with CMOS matrix whose size is 36 x 24 mm (full frame) and the full resolution of 5616 x 3744 pixels (21.1 megapixels, where the size of a single pixel is 6.4μm). The professional lens - Canon 50 mm f/1.2 L EF USM with the nominal focal distance of 50 mm was used in the project. Other devices included Leica TC1800 electronic tachymeter, a micrometric table, a surveying tripod, three-axis photographic head - Manfrotto 405 Geared Head, geodetic tripod for engineering purposes with a jib, two tribrachs, two targets and the observation pillar. It is also possible to use WFT-E4 II WiFi transmitter to send images to a server or a computer hard drive straight after they are taken using a wireless Internet connection. It is also feasible to operate the camera remotely.

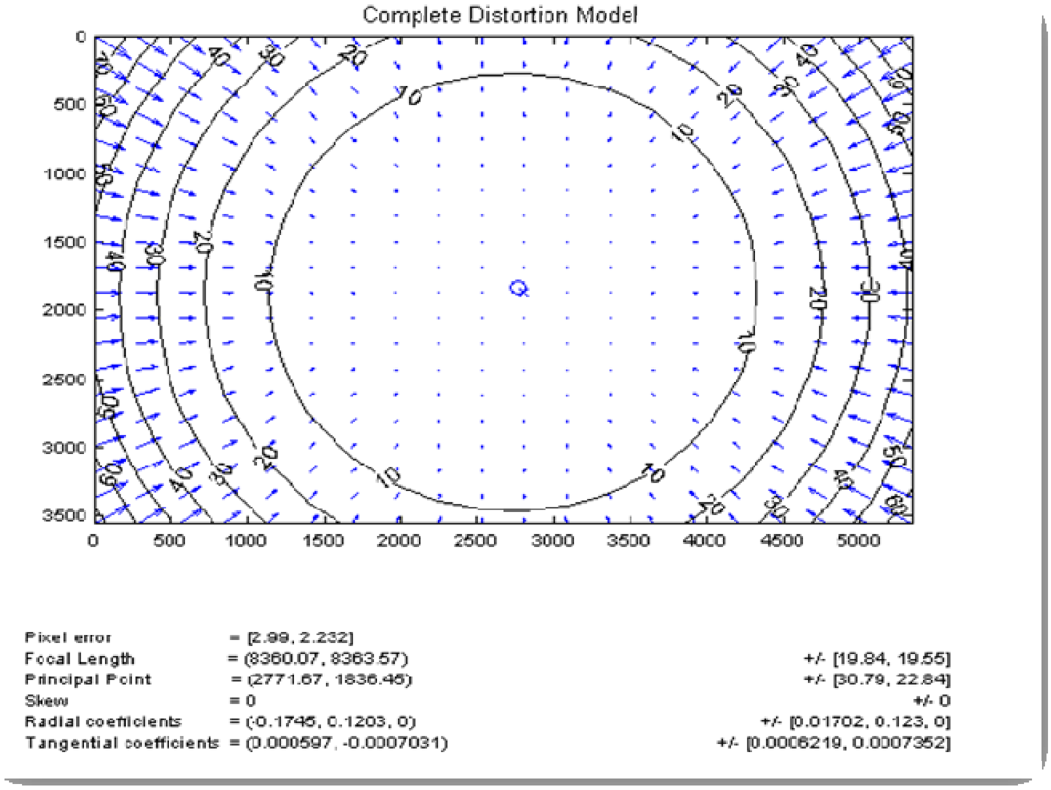


Fig. 7 The calibration results for Canon EOS 5D Mark II with 50 mm telescope for the focal distance of 0.82 m.

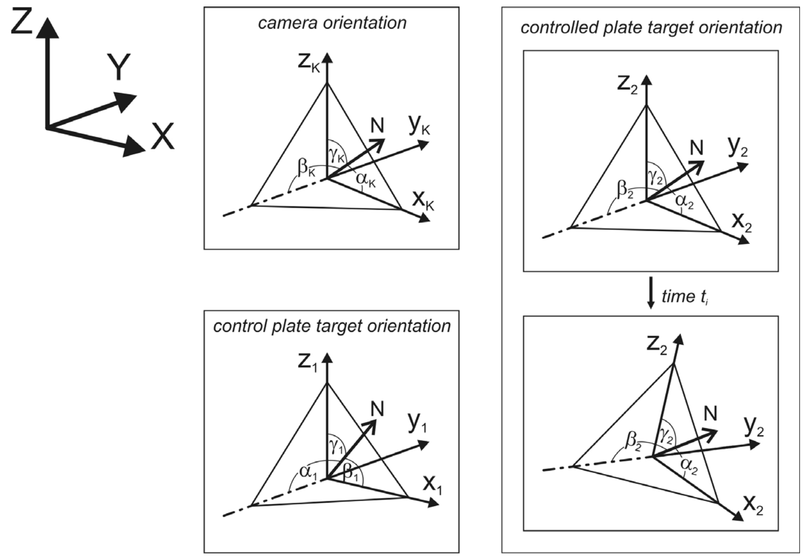
Before the measurements a tribrach with a micrometric table were installed on the observation pillar. A tachymeter was then set on the table. A passive plate target described in the article was installed on the tachymeter telescope (Fig. 6). In the neighbourhood of the pillar, a tribrach with the second passive plate target was installed on the head of the engineering tripod. This target after levelling and positioning at the set height played the role of the orientation (control) target for the given set-up of the camera. Afterwards, the tachymeter was levelled, the readings from the graduations of the micrometric screws of the table and initial readings (zenith angle, horizontal direction) at the set position of the telescope were recorded. In the distance of about 1 metre from measuring targets, the photographic head was set on the surveying tripod and coupled with the semi-metric camera. It was necessary to arrange the measuring devices in this way to ensure the appropriate parameters for photographing the targets. These parameters result from the preliminary accuracy analyses, where the scale of pictures and the accuracy of measuring points in pictures were considered. In order to determine the position of survey points on the plate target with the accuracy of up to hundredth parts of a millimetre, the scale of registered images of the plate targets should not exceed 1:20. When the pixel size is 6.4μm and when the adopted photographic parameters are valid (nominal focal distance f=50 mm) the distance between the target and the kamera is ca. 1 m and the accuracy of measuring a single point in the picture averages ±0.12 mm. When a multi-point plate target is used the accuracy will increase 2 to 4 times, which ensures that the mean accuracy of measurement will be between 0.25 and 0.5 pixel.

The camera needs to be calibrated prior to measurements. It enables to establish the elements of the internal orientation as well as distortion parameters of the optical system in the camera (Zhang, 2000). Calibration was done for 33 different locations and settings of the targets with respect to the location of camera (Fig. 6). The calibration results are presented in Figure 7 in the form of distortion diagram and the values of geometrical parameters of the camera are given in pixels.

The experimental works involved taking pictures of plate targets for the set values of the zenith angle and horizontal direction of the tachymeter telescope and shifts of the micrometric table in the horizontal plane. These measurements were carried out for three different setting-ups of the camera. The measurement results for the set values of angles, directions and displacements were registered in the survey documentation. Table 1 presents the results of 46 surveys for 3 independent settings of the camera. These

Table 1 Comparison of the values of displacements in the horizontal plane and rotations of the plate target measured with micrometric screws of the table and using the graduation of the horizontal and vertical circles of the tachymeter.

№	Number of photos	Displacements		Rotation		Setting
		longitudinal *dy*	perpendicular *dx*	vertical *V*	horizontal *Hz*	
		[mm]	[mm]	[g]	[g]	
1	1429	10.00	5.00	99.6362	**0.0000**	1
2	1430	10.00	5.00	99.6367	**399.0012**	
3	1431	10.00	5.00	99.6372	**398.0029**	
4	1432	10.00	5.00	99.6377	**396.9995**	
5	1433	10.00	5.00	99.6382	**396.0021**	
6	1434	10.00	5.00	99.6386	**395.0013**	
7	1435	10.00	5.00	99.6403	**394.0044**	
8	1436	10.00	5.00	99.6403	**394.0019**	2
9	1437	10.00	5.00	99.6399	**395.0009**	
10	1438	10.00	5.00	99.6388	**397.0025**	
11	1439	10.00	5.00	99.6374	**399.0008**	
12	1440	10.00	5.00	99.6368	**0.0021**	
13	1441	10.00	5.00	99.6363	**1.0015**	
14	1442	10.00	5.00	99.6357	**2.0005**	
15	1443	10.00	5.00	99.6353	**3.0001**	
16	1444	10.00	5.00	99.6347	**4.0014**	
17	1445	10.00	5.00	**99.6370**	**0.0027**	
18	1446	10.00	5.00	**99.0012**	0.0010	
19	1447	10.00	5.00	**98.0029**	0.0016	
20	1448	10.00	5.00	**97.0000**	0.0009	3
21	1449	10.00	5.00	**96.0022**	0.0002	
22	1450	10.00	5.00	**95.0004**	399.9996	
23	1451	10.00	5.00	**94.0010**	399.9989	
24	1452	10.00	5.00	**94.0010**	399.9989	
25	1453	10.00	5.00	**100.0014**	0.0040	
26	1454	10.00	5.00	**101.0030**	0.0046	
27	1455	10.00	5.00	**102.0015**	0.0052	
28	1456	10.00	5.00	**103.0009**	0.0058	
29	1457	10.00	5.00	**104.0027**	0.0065	
30	1458	10.00	5.00	**105.0012**	0.0071	
31	1459	**10.00**	5.00	**100.0031**	0.0041	
32	1460	**8.00**	5.00	100.0011	0.0043	
33	1461	**6.00**	5.00	99.9999	0.0040	
34	1462	**4.00**	5.00	99.9986	0.0041	
35	1463	**10.00**	5.00	100.0033	0.0041	
36	1464	**12.00**	5.00	100.0094	0.0041	
37	1465	**14.00**	5.00	100.0088	0.0041	
38	1466	**10.00**	**5.00**	100.0034	0.0041	
39	1467	10.00	**3.00**	100.0042	0.0041	
40	1468	10.00	**1.00**	100.0046	0.0041	
41	1469	10.00	**5.00**	100.0036	0.0042	
42	1470	10.00	**7.00**	100.0034	0.0042	
43	1471	10.00	**9.00**	100.0031	0.0042	
44	1472	10.00	**11.00**	100.0026	0.0042	
45	1473	10.00	**5.00**	100.0033	0.0042	
46	1480	10.00	**5.00**	100.0010	0.0017	



equation of the normal plane:

$$x \cos\alpha + z \cos\beta + y \cos\gamma + p = 0$$

Fig. 8 Diagram illustrating the location of the normal vector and its versors in local coordinates XYZ.

results were used to analyse the accuracy of measurements, their repeatability as well as displacements and rotations of the targets that were established on the strength of this data. The analysis of results and the accuracy evaluation are discussed below.

The columns in Table 1 include geometrical values (presented against the grey background) such as direction (*Hz*), angle (*V*) displacements (*dx* and *dy*), which were changed during the experimental works. The rows in the table contain the results of selected measurements that were used to determine the repeatability accuracy for the observations.

The measurements were done in the registered images of the plate targets using the proprietary program that enabled to determine the coordinates of survey points in the local orthogonal coordinate system (Fig. 6a). The coordinates of survey points (corners of the grid) were used as a basis to determine plane normal vectors of the two plate targets in all set locations (Fig. 8). For every normal vector, values of versors (α, β and γ) were determined. The coordinates were also used to establish the centre of gravity for targets (X, Y, Z) in the local coordinate system.

Table 2 presents the results of calculating the parameters that characterise the situation of the left static target (control plate target) and the right mobile target (controlled plate target). Computations were done for the selected target locations. The results were used to determine the mean measurement errors which confirm the repeatability accuracy of photogrammetric measurements in the registered images. In statistics, the mean error of measurement is known as the standard deviation.

The values of parameters in Table 2 indicate a small difference in the repeatability of results of photogrammetric measurement registered in the images of both the control (static) target and the (controlled) mobile target. The analysis of measurement results performed for six images of the left target suggests that the repeatability error for angular values being determined (where the measuring distance is 816 mm) is $\pm 50^{cc}$ and for linear values ±0.02 mm. Similarly, when seven images of the right (mobile) target are examined, the repeatability error for angular values is $\pm 83^{cc}$ and for linear values it is ±0.02mm.

Table 3 presents calculated parameters that characterise the location of the right mobile controlled target with respect to the left static control target. For the purpose of this comparison mean values of determined parameters were adopted for the left (controlled) target (Table 2).

Computations were done for seven selected target locations. The results obtained enabled us to determine the mean errors for the relative positions of targets. Errors of the angular parameters $(\Delta\alpha, \Delta\beta, \Delta\gamma)$ are between $\pm 20^{cc}$ and $\pm 112^{cc}$ (when the mean measurement distance is 812 mm) while the mean errors of linear parameters $(\Delta X, \Delta Y, \Delta Z)$ are ±0.018 mm, ±0.015 mm and ±0.008 mm respectively. The error values confirm a very high accuracy of relative photogrammetric measurements on the photographs.

For the selected outcomes of measurements in the images and the set movements of micrometric screw of the right controlled target that correspond to

Table 2 Comparison of parameters illustrating the locations of control (left) and controlled (right) plate targets and mean errors of positioning the targets using the photogrammetric Metod.

Control plate target									
Parameter		**1448**	**1453**	**1459**	**1466**	**1473**	**1480**	**Mean value**	**m_0**
α_L	**[g]**	**100.1785**	100.1715	100.1766	100.1660	100.1750	100.1778	100.1742	**0.0047**
β_L	[g]	100.9483	100.9547	100.9512	100.9622	100.9558	100.9609	100.9555	**0.0054**
γ_L	[g]	0.9649	0.9700	0.9674	0.9765	0.9717	0.9772	0.9713	**0.0049**
X_L	[mm]	-153.711	-153.7105	-153.721	-153.723	-153.730	-153.736	-153.723	**0.009**
Y_L	[mm]	816.385	816.400	816.401	816.398	816.426	816.427	816.406	**0.017**
Z_L	[mm]	-28.281	-28.295	-28.302	-28.318	-28.334	-28.337	-28.311	**0.022**

Controlled plate target										
Parameter		**1453**	**1459**	**1463**	**1466**	**1469**	**1473**	**1480**	**Mean value**	**m_0**
α_R	[g]	95.4423	95.4486	95.4471	95.4493	95.4500	95.4457	95.4785	95.4516	**0.0121**
β_R	[g]	97.8281	97.8275	97.8291	97.8313	97.8313	97.8332	97.8280	97.8298	**0.0021**
γ_R	[g]	5.0503	5.0449	5.0456	5.0427	5.0420	5.0451	5.0177	5.0412	**0.0107**
X_R	[mm]	139.905	139.918	139.926	139.906	139.901	139.901	139.864	139.903	**0.020**
Y_R	[mm]	808.397	808.409	808.393	808.406	808.409	808.387	808.410	808.402	**0.009**
Z_R	[mm]	-56.511	-56.516	-56.526	-56.532	-56.540	-56.549	-56.552	-56.532	**0.016**

Table 3 Comparison of the calculated parameters characterising the position of the right mobile controlled target with respect to the left static control target and repeatability errors for the positions of targets established on the basis of photogrammetric measurements.

Parameter		**1453**	**1459**	**1463**	**1466**	**1469**	**1473**	**1480**	**Mean value**	**m_0**
$\Delta\alpha=\alpha_R-\alpha_{Lm}$	[g]	-4.7319	-4.7257	-4.7271	-4.7250	-4.7243	-4.7286	-4.6958	**-4.7226**	**0.0112**
$\Delta\beta=\beta_R-\beta_{Lm}$	[g]	-3.1274	-3.1280	-3.1264	-3.1242	-3.1242	-3.1223	-3.1275	**-3.1257**	**0.0020**
$\Delta\gamma=\gamma_R-\gamma_{Lm}$	[g]	4.0790	4.0736	4.0743	4.0714	4.0708	4.0738	4.0464	**4.0699**	**0.0099**
$\Delta X= X_R-Y_{Lm}$	[mm]	293.628	293.640	293.649	293.629	293.623	293.624	293.586	**293.626**	**0.018**
$\Delta Y= Y_R- Y_{Lm}$	[mm]	-32.244	-32.249	-32.259	-32.265	-32.273	-32.282	-32.285	**-32.265**	**0.015**
$\Delta Z= Z_R- Z_{Lm}$	[mm]	-8.009	-7.997	-8.013	-8.001	-7.997	-8.019	-7.996	**-8.005**	**0.008**

these outcomes (and which are presented in Table 1), the accuracy analysis was carried out on the strength of the coordinate differences. The results of analyses are presented in Table 4.

d_p value (Formula 1) was determined on the basis of measurements with micrometric screws in the set locations: current location (dx_i, dy_i) and the previous location (dx_{i-1}, dy_{i-1}) of the controlled plate target.

$$d_p = \sqrt{(dx_i - dx_{i-1})^2 + (dy_i - dy_{i-1})^2} \quad (1)$$

D_p value (Formula 2) was determined on the strength of photogrammetric measurements on the images that correspond to the current location (Dx_i, Dy_i, Dz_i) and the previous location (Dx_{i-1}, Dy_{i-1}, Dz_{i-1}) of the examined controlled target.

$$D_p = \sqrt{(Dx_i - Dx_{i-1})^2 + (Dy_i - Dy_{i-1})^2 + (Dz_i - Dz_{i-1})^2} \quad (2)$$

Based on calculations of 14 displacement differences (marked with Δ operator) between the

Table 4 The accuracy evaluation for displacements of the controlled plate target measured using the photogrammetric method with respect to the displacements of the plate target set using micrometric screws.

№	**Number of photos**	**Position and relative displacements of the controlled plate target**							**The displacement differences**
		inflicted by the micrometric screws			**measured using the photogrammetric method**				
		dy	***dx***	**Relative displacement d_p**	**X_R**	**Y_R**	**Z_R**	**Relative displacement D_P**	**$\Delta = D_P - d_p$**
		[mm]	**[mm]**	**[mm]**	**[mm]**	**[mm]**	**[mm]**	**[mm]**	**[mm]**
1	1459	10.00	5.00	**-**	139.918	808.409	-56.516	**-**	**-**
2	1460	8.00	5.00	**2.00**	139.821	810.404	-56.522	**1.997**	**-0.003**
3	1461	6.00	5.00	**2.00**	139.689	812.431	-56.527	**2.030**	**0.030**
4	1462	4.00	5.00	**2.00**	139.613	814.430	-56.533	**2.001**	**0.001**
5	1463	10.00	5.00	**6.00**	139.926	808.393	-56.526	**6.045**	**0.045**
6	1464	12.00	5.00	**2.00**	139.950	806.346	-56.531	**2.047**	**0.047**
7	1465	14.00	5.00	**2.00**	140.013	804.352	-56.532	**1.995**	**-0.005**
8	1466	10.00	5.00	**4.00**	139.906	808.406	-56.532	**4.055**	**0.055**
9	1467	10.00	3.00	**2.00**	141.916	808.428	-56.533	**2.010**	**0.010**
10	1468	10.00	1.00	**2.00**	143.949	808.473	-56.533	**2.033**	**0.033**
11	1469	10.00	5.00	**4.00**	139.901	808.409	-56.540	**4.049**	**0.049**
12	1470	10.00	7.00	**2.00**	137.855	808.357	-56.544	**2.047**	**0.047**
13	1471	10.00	9.00	**2.00**	135.856	808.327	-56.542	**1.999**	**-0.001**
14	1472	10.00	11.00	**2.00**	133.828	808.285	-56.547	**2.029**	**0.029**
15	1473	10.00	5.00	**6.00**	139.901	808.387	-56.549	**6.074**	**0.074**
Mean error of the relative displacement measurement m_D									**± 0.027**

position of the right target, which was determined using the photogrammetric method and the set micrometric screws (Formula 3), the mean error of the relative displacement measurement (m_d) was determined using formula 4.

$$\Delta = D_p - d_p \qquad (3)$$

$$m_D = \sqrt{\frac{\sum_{i=1}^{n}(\Delta\Delta)}{2n}} \qquad (4)$$

The value of the error was $m_D = \pm 0.027$mm.

4. CONCLUSION

The authors designed and created the kit of measuring devices discussed in the article with the aim to determine relative and absolute displacements of rock blocks using the photogrammetric method. The important feature of photogrammetric measurements was that they enabled to determine displacements in a 3D space consisting of points that were located on the plate targets. The measurements of the series of single images were carried out for this purpose. The aim of the experimental laboratory works was to calibrate the camera. Then, the accuracy of photogrammetric measurements in the series of images which were taken for two plate targets placed in different spots could be established. The second research aim was to determine geometric parameters (tensors) that characterise the mutual location of targets in the space. The accuracy analyses were performed using selected observations.

Table 2 presents the results of calculating the parameters that characterise the location of the left static target (control target) and the right mobile target (controlled target). Computations were done for the selected target locations. The results were used to determine the mean measurement errors which confirm the repeatability accuracy of photogrammetric measurements in the registered images.

The research and experimental works and the accuracy analyses lead to the following conclusions:

1. The repeatability error for angular values determined for the two targets (where the distance is 0.82 m) is $\pm 50^{cc}$ while the error for linear values is ±0.02 mm.
2. Mean errors of relative positions of targets for angular parameters $(\Delta\alpha, \Delta\beta, \Delta\gamma)$ and the measuring distance of 0.82 m are between $\pm 20^{cc}$ and $\pm 112^{cc}$ and for linear parameters $(\Delta X, \Delta Y, \Delta Z)$ they are ±0.018mm, ±0.015mm and ±0.008mm respectively.
3. Mean error of the relative target displacement measurement determined on the strength of the set movements of micrometric screws m_D was ±0.027 mm.
4. By installing fixed targets on the object, changes occurring over a period of time may be monitored and the current state of the object may be assessed.
5. The measuring devices and instruments designed in this research may be applied in different combinations depending on the type and the structure of the object. This allows to determine relative (or/and absolute) linear and angular displacements.

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