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NORMAL AND CONVERGENT METHODS OF SURVEY FOR INVENTORY AND CERTIFICATION OF CULTURAL STRUCTURES

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Abstract. The article aims to study the use of normal and convergent stereo-photographic techniques to determine physical condition of a building, to compare errors obtained using a digital non-specialized camera, and use these methods in the inventory and certification of real estate. Monitoring architectural monuments is currently one of the most urgent problems. The development of large cities in which architectural monuments are under threat of destruction requires modern and effective technology for monitoring which is possible using low-cost photogrammetry methods: digital images and cheap software. The development of digital cameras into terrestrial photogrammetry resulted in fundamentally new methods and photogrammetric technologies. In case of monitoring objects of small sizes, such as architectural monuments, the cost of shooting equipment is one of the most significant factors, which reduces the cost of work, therefore, in the vast majority of cases, only digital non-metric cameras are used for shooting. The most significant problem is the calibration of digital non-metric cameras. Currently, a huge number of options for calibrating digital cameras have been developed. These options differ in calibration method, type of test object, type of mathematical model for accounting for distortion (algebraic, physical or hybrid model) The present study how that accuracy of the convergent method is almost 2 times higher than that of the normal photogrammetric survey method and provides a large survey overlap area. Comparing all the indicators and characteristics of these methods, we concluded the feasibility, high profitability, and low complexity of the convergent method of stereo photography to perform inventory and certification of real estate. We found that when surveying building using convergent method it is necessary to use 2 times fewer stations than when surveying by normal method. Thus, the convergent method is 2 times faster and more efficiently.

Keywords: inventory and certification of buildings and structures, convergent method, normal method, non-metric camera, stereo photographic method, monitoring of architectural monuments.

Introduction

Buildings and structures are subject to periodic inspection for the resons of safety. During the reconstruction of buildings and monitoring their possible deformations, it is advisable to use photogrammetric survey methods. The use of photogrammetric methods ensures a tim-efficient approach and with robust accuracy. Inventory and certification is of crucial importance not only to ensure the registration of real estate but also to reflect their quality characteristics, especially to ensure reliable operation of industrial, residential, social, cultural and other facilities, regardless of their subordination and ownership. Performing such survey allows determining the number and subordination of real estate objects, which are in the unsatisfactory technical or emergency condition, in order to compile a register, which is a prerequisite for the implementation of measures to correct the state of civil objects. However, as a rule, the decision on the operation of facilities is made without local engineering measures, which negatively affects the adoption of effective and timely decisions for further use of the real estate. In view of all this, an information system for detecting and monitoring the status of real estate is needed. That is, it is necessary to organize an appropriate system for monitoring quality of buildings and structures and organizing their maintenance. Besides, it is also necessary to consider regional environmental setting of the study area. Therefore, identifying, monitoring, analysing and forecasting the shortcomings of technical conditions of real estate is very important. In particular, such measures are necessary in view of the growing importance

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of modernization and reconstruction of major buildings and structures (Dorozhynsky, 2002).

Regulatory documents (Verkhovna Rada of Ukraine, 1999, 2011) provide a wide range of measures to solve this problem. However, there is no clear instruction for monitoring compliance with all the standards. The status and powers of subjects and participants of legal relations in the field of accounting and technical inventory of real estate have been changed, which deprives local governments of the possibility of monitoring the preservation of the housing stock (DBN, 1997, 2009).

However, the following issues remain unresolved:

- identifying the facts of the unauthorized construction;
- pricing of technical inventory (the tariffs of technical inventory bureau are approved by local governments);
- transfer of technical inventory materials from local governments to the archives of the state registration authority;
- admission of private entities to carry out technical inventory work on real estate objects, such as nuclear power plants, heat and hydroelectric power stations, military units, bomb shelters, facilities of the Ministry of Emergency Situations, pre-trial detention facilities, etc.

The State Register of Immovable Monuments of Ukraine, created in 2000, is updated extremely slowly and does not contain comprehensive information about real estate objects that would give a clear idea of the following issues:

- the degree of problematic attraction;
- the priority of the necessary repair or restoration work;
- attracting relevant and competent specialists and the like.

Public organizations are much more active to protect and preserve spiritual and religious heritage. For example, in 2012 in Lviv region on the initiative of the Interfaith Commission of the Ukrainian Society for the Protection of Historical and Cultural Monuments and group of scientists from the National University "Lviv Polytechnic", the implementation of the project on inventory and certification of church property in the region using laser scanning technology was initiated. Its purpose is to record and describe the corresponding archeological and historical heritage in detail. Nevertheless, this project presents rather an exception than a rule. The experience of Lviv residents is appropriate to test it in other regions of the country.

Thus, the main problems of conducting an inventory and certification of real estate including the following concerns:

- lack of systematic organization of monitoring the state of buildings and structures;
- insufficient graphic fixation of real estate;
- inadequate financing of work;
- lack of regulatory authority.

In Mata et al. (2004) digital surveying is used to plan the building for restoration work with a case of 12th-century church where restoration of front plan and interior are required. The results of this research presented reconstruction of the Church of St. Domingo in Spain, which is almost destroyed nowadays. An effective technology to provide the missing data on the facades of houses is to obtain images from ground images and project them on polygonally constructed facades of the created models, which is emphasized in other works (e.g., Kada, 2004; Kersten et al., 2004). Since manual method of obtaining plans and corresponding placement is time-consuming, an automatic method that uses visualization of modern 3-D graphic electronic plans is proposed.

Therefore, there is a need to expand the possibilities of using modern methods of survey for more efficient performance of survey However, to achieve this goal, it is necessary to improve the regulatory framework in terms of inventory and certification of real estate.

The aim of the study is the peculiarities of using photogrammetric methods when performing an inventory and certification of buildings and structures of religious buildings, located in the village of Ivano-Frankovo, Lviv region. Despite the remote location of this structure on the outskirts of the village, it is situated in the area of easy pedestrian and transport accessibility to the centre of the village, district and regional centres, which makes it attractive to inhabitants and visitors. The specific objective of this study is to use both normal and convergent methods of stereo photography, in order to determine physical condition of a real estate object, which is a religious building (church). With this objective we aimed to compare the two methods: to obtain mean square errors with a digital non-specialized camera and to justify the use of these methods in the inventory and certification of real estate objects.

1. Materials and methods

To perform the inventory and certification of real estate, the workflow included necessary steps to solve the following tasks:

- to specify the dimensions of the cross-sections of structural elements and schemes of their loads;
- to determine actual physical and mechanical characteristics of the materials and structures;
- to identify and measure the offset in the plan, precipitation, incline, deflections, the presence of corrosion, etc., using graphical design of defects and structural damage;
- to determine the dimensions of joint deformations, crack width and depth, reinforcement sections, thickness of the concrete protective layer, etc.;
- to analyse and monitor results from previous detailed surveys.

To achieve these goals, three main methods have been used: the traditional surveying method, the laser scanning method, and the photogrammetric methods (Ministry of Justice of Ukraine, 1998).

2. Traditional surveying method

To determine the subsidence of structures, the method of geometric levelling, which is characterized by high accuracy and speed of measurements, is the most widely used. Using this method, the difference between the points at a distance of 5–10 m can be determined with an accuracy of 0.05–0.1 mm, and at a distance of hundreds of meters – with an accuracy of 0.5 mm. The levelling of I and II classes to determine the drawdown of the industrial and residential buildings is used. The root mean square error (RMS) of elevations at the station in these cases are 0.4 and 0.5 mm, respectively. The deformation point marks for the entire observation period are determined relative to the initial reference mark or group of reference marks. The results obtained are balanced. The actual accuracy of marks is evaluated for their differences in cycles. The location of real estate objects is plotted. The stability of the height base benchmarks in the process of observing the displacements in each measurement cycle is monitored. For this purpose, all of them are included in the closed polygon and such constructions make a deformation network of the first order. To determine the heights of the deformation marks, they are included in levelling moves, which are based on the benchmarks of the deformation network of the first order. These constructions are a second-order deformation network. Linear-angular constructions are created in form of special networks of triangulation and trilateration, courses of polygonometry, combined networks, angular and linear serifs, as well as networks from the extended triangles with the measured parties and heights. Modern electronic total stations can simultaneously measure horizontal and vertical angles, distances and elevations. The principle of operation of the total station is based on the reflection of narrowly directed laser beam, which reflects the target and measures the distance to it. The reflector is a special prism mounted on the surface of the object. Measuring vertical and horizontal angles enables to calculate the three-dimensional spatial coordinates of the display point. The advent of new total stations, which can work without special reflectors has revolutionized geodesy. Electronic total stations allow creating of fully automated mapping systems. It is also possible to use the tacheometric data in conjunction with the data obtained from satellite receivers (Tsioukas, 2007; Gruen & Akca, 2008; Kedzierski & Walczykowski, 2007).

3. Laser scanning method

Laser scanning is a method that allows creating a digital model of the surrounding space, representing it as a set of points with spatial coordinates. The main difference from the electronic total station is a significantly higher measurement speed (over 5000 measurements per second) and the density of the "cloud" of points (up to tens of points per 1 cm of the surface). The object model obtained after measurements is a "cloud" of points (from hundreds of thousands to several million), which has coordinates with an accuracy of several millimetres (Shults et al., 2017). The main goal of laser scanning technology is to determine spatial coordinates of points on the surface of the object, which is performed by measuring the distance to all identified points with a laser rangefinder. The operation of laser scanner is controlled by a laptop computer and a special software. The obtained values of the coordinates of the points received from scanner are transferred to the computer and stored in a special database. Terrestrial laser scanners are often classified according to the principle of determining spatial coordinates: pulsed, phase and triangulation. The classification of the terrestrial laser scanners is presented in Table 1 (Kraus, 2001; Katushkov et al., 2006; Dubinovsky, 1982; Mogilny & Lunev, 2007).

Table 1. Classification of terrestrial laser scanners according to the principle of distance measurement

The measuring principle	Maximum measuring distance, m	Distance accuracy, mm	Manufacturers
Pulse method	50–300	up to 10	Callidus, Leica, Trimble, Optech, Rieql
	up to 1000	up to 20	Optech, Rieql
Phase method	up to 100	up to 10	IQSun, Leica, Vislmaqe, Z + F
Optical triangulation	up to 5	up to 1	Trimble, Minolta

The pulse scanners implement a method for determining distances based on accurately determining the time of pulse passage to the target and back. The main advantage of pulse scanners is a long measurement range (several hundred of meters), since this method uses a light pulse to directly measure the distance. In contrast, the range of the phase scanners is limited to only 100 m. In scanners of this type, the distance is determined by measuring the phase shift of the emitted and reflected signals. Unlike the pulsed method, high laser power is not required and therefore distances are measured with an error of a few millimetres, because this method uses a modulated light signal to determine the distance. The measurement speed of phase scanners (several orders of magnitude) exceeds the speed of pulse scanners. The triangulation method is implemented in high-precision scanners. A design feature of such scanners is the diversity of a known distance (basis) between the emitter and signal receiver. Such scanners enable to achieve the ultra-high accuracy of measurements in tenths and even hundredths of a millimetre but at short distances (several meters) (Shults et al., 2015, 2017).

4. Photogrammetric methods

The disadvantage of the above methods for measuring subsidence, horizontal displacements and rolls, is that only one type of displacement is measured: either vertical or horizontal. In contrast to these measurement methods, the photogrammetric survey method allows to simultaneously measure the displacement of an unlimited number of points of a building or a structure in the two directions of the coordinate axes: vertically and part of the horizontal displacement using one device. For example, the stereophotogrammetric method allows surveying in three directions (Glotov & Pashchetnik, 2014).

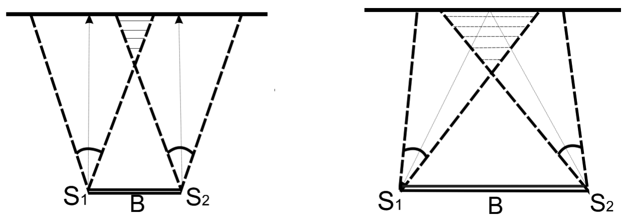
The error in determining the offset values mainly depends on the following factors: the invariance of the position of the photography stations, the correct orientation of the optical axis of the camera in space, and the length of the basis of photography. To achieve uniform coverage of observations, the photographing bases (or several bases) are placed at the optimal distance from the building. This is aimed at creating direct visibility between the ends of the bases for a more precise coordination. As a result, this allows obtaining the accuracy of building deformation at a distance of 10–20 m structures at the level of up to 1–3 mm. The observation points are fixed on buildings by deformation marks in form of points with an indication of number. For this purpose, points of door and window openings or other structural elements that can be recognized are used. For a more detailed analysis of deformations of the buildings and structures detected by the photogrammetric method, it is recommended to compare them with the results obtained by the high-precision geometric levelling method (Glotov, 1998).

Digital measuring devices based on the use of CCD arrays in combination with computer technology (nonmetric digital cameras) are now widely used. When determining the deformations of buildings and structures, the survey of cracks by the camera on the background of the millimetre ruler significanlty simplifies the work and provides high efficiency and accuracy of measurements with precision up to 0.05–0.1 mm. The non-metric digital cameras must be calibrated for ground stereo imaging to obtain the dimensional drawings of architectural and engineering objects. It requires using the coordinates of a large number of marked points of the object, determined by an electronic total station (Dorozhynsky, 2002, 2003; Glotov & Pashchetnik, 2014).

When performing an inventory of buildings and structures, the use of normal and convergent methods of photogrammetric survey is generally recommended. The normal shooting method is a method of shooting (or photographing) an object of observation, in which optical axes of the left and right cameras are set horizontally and perpendicular to the photographing basis. The convergent shooting method is a method of shooting (photographing) an object of observation, in which the optical axes of the left and right cameras intersect.

With the normal shooting method, the optical axes of the left and right cameras are set horizontally and perpendicular to basis B, the image plane occupies a vertical position. The normal method of shooting is used more often because it provides the most accurate results, simplifies mathematical processing, and has a better stereo effect compared to the other ones (Figure 1) (Aydar et al., 2007; Antoniou, 2007; Kalantari & Kasser, 2007; Bernardini & Fangi, 2007; Glotov & Pashchetnik, 2014).

With the convergent shooting method, the optical axes of the left and right images intersect at an angle γ, ensuring a complete overlap of the object images (Figure 1).



a) b)

Figure 1. Normal: a – and convergent; b – survey methods

To compare the accuracy of normal and convergent survey methods and modelling the images, it is recommended to use a program for generating simulated images (Figure 2).

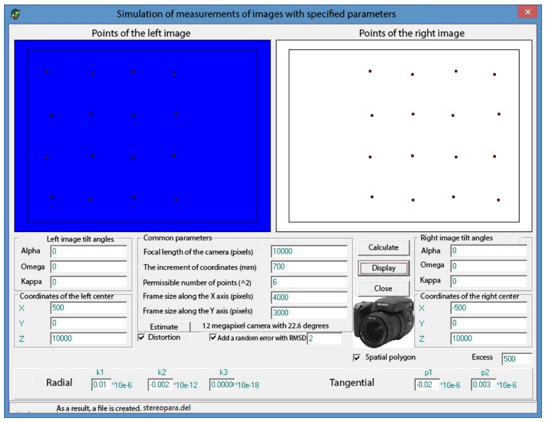


Figure 2. The menu window of the program for simulation of measurements of images

General parameters include the characteristics of the camera (focal length *f*, frame size along the X, Y-axis) and the parameters of the experimental polygon (the number of points and the distance between them) (Figures 2, 3). Based on the entered parameters, it is possible to estimate the characteristics of the camera, namely, the angle of capture and the number of megapixels. To simulate shooting cases, the exterior orientation parameters are set as follows: left and right camera position points (S_l, S_r), angles of inclination of the left and right images (α, ω, κ). It is also possible to use the parameters that consider distortion at the given parameters, modelling situations when the abovementioned values have a root-mean-square error and a volumetric polygon modelling (Figure 3) (Dorozhynsky, 2003).

A file with the *.del extension is the result of the generating model images using the program. This file will be further used in the Block MSG program to process the obtained research results. To compare the accuracy of normal and convergent methods, we built the models and found that the accuracy of the photogrammetric work depends on the shooting parameters (distance to object Y,

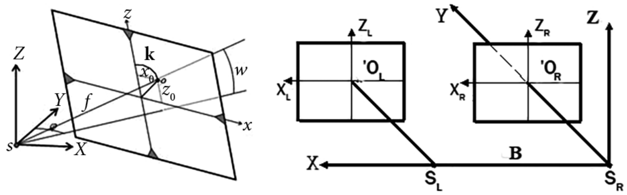


Figure 3. Graphic interpretation of the parameters set in the program for modelling the mock-up images

shooting base, shooting type, camera focal length *f*, frame format), the accuracy of image measurement, the use of corrections for erroneous elements with external and internal orientation, etc.

The geodetic workflow was performed with the use of the Vizir 3D software complex designed for installation of the high-precision geometrical parameters of various technological equipment and its adjustment in the design position. A special feature of this complex is the ability to work online with the high-precision electronic total stations of the NET, SRX and SET series from Sokkia. At the same time, the complex has all the capabilities of the MGSet program, which is designed to build, balance and pre-calculate the accuracy of the horizontal, vertical and compilation networks of arbitrary configuration with tacheometric surveys, which allows measurements of individual structural elements, including unrelated ones.

To increase the accuracy of the geodetic measurements, the software complex "Vizir 3D" operated in synchronous mode with two total stations, which allowed to achieve measurement accuracy up to 0.1 mm. The use of the online mode of measurements and processing of measurement results made it possible to increase the efficiency of processing the performed measurements, to obtain final results and to correct the position and shape of the research object. To carry out these works, we run a theodolite traverse, consisting of 7 points (Figure 4).

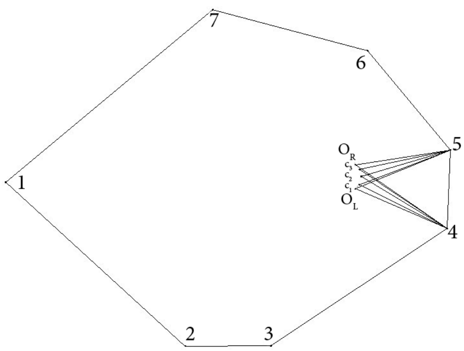


Figure 4. Scheme of the geodetic network

Five marks are fixed on the facade of the building of the old church. Their coordinates were measured with a tacheometer from the two points (Figure 5).

The survey of the facade of the church building was performed in the two ways by convergent and normal survey methods to ensure complete overlap of the object of study (Figure 6).

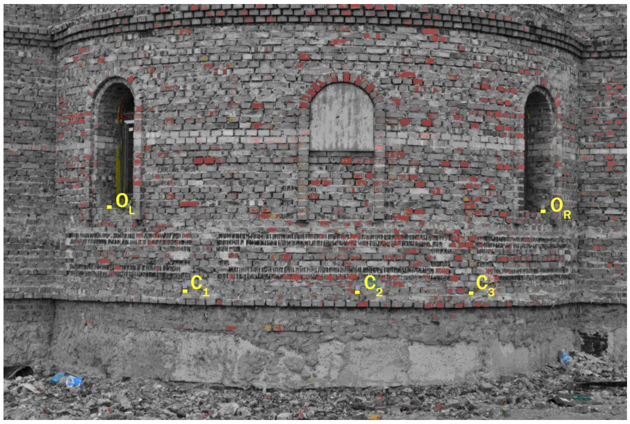


Figure 5. The facade of the church building

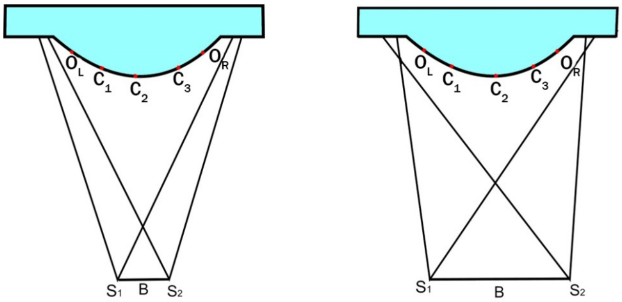


Figure 6. Scheme of the stereo photography. Normal and convergent cases of surveying the facade of a religious building

The stereo photography was performed using the Olympus E20P digital camera with the appropriate calculations of the internal orientation elements.

Further processing of the results was performed using a digital photogrammetric complex Digitals/Delta. To build a digital model of the object, we adapted the following stepwise workflow:

1. Preparation of the initial data:
- analysis of the source data (digital images, photography parameters, coordinates of the reference points);
- correction of digital images in the "DipEdit" program;
- setting the parameters of the digital camera in the "Camera" program;
- formation of the photography route "Block".

2. Image measurement:
- measurement of the internal orientation points of images (coordinate marks);
- measurement of the mutual orientation points of images;
- measurement of the reference points;
- analysis and adjustment of measurements;
- Balancing the measurement results in the "BlockMSG" program (Shults et al., 2019).

During performing these works, two pairs of images of normal and convergent cases of surveying were obtained. The coordinates of the reference points and their errors are presented in Table 2.

Table 2. Coordinates of reference points and their errors

No	Point name	X, m	Y, m	Z, m	Mx, m	My, m	Mz, m
1	O_L	–1.4218	76.4686	2.2187	0.002	0.0014	0.0003
2	C_1	–0.5156	77.2908	1.2494	0.002	0.0014	0.0003
2	C_2	1.4146	77.7293	1.2614	0.002	0.0014	0.0003
4	C_3	2.7845	77.3826	1.2596	0.002	0.0014	0.0003
5	O_R	3.8527	76.4688	2.2437	0.002	0.0014	0.0003

Files of digital images are first opened in the program DipEdit, where their radiometric correction is performed (Figure 7).

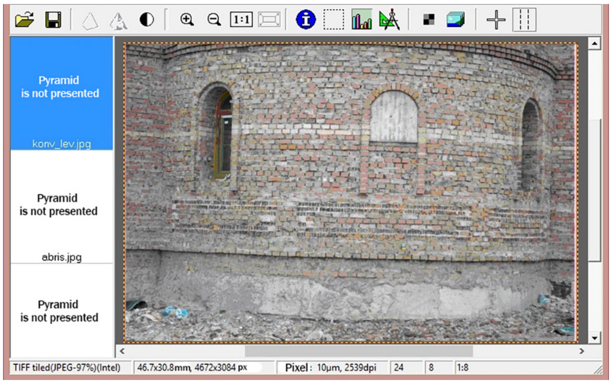


Figure 7. The main interface of the module DipEdit

After opening, we saved all images in the "TIF tiled" format using the "File/Save All As" command in the program menu. The "Create Pyramid" function allows the program to create images of different resolutions (8 levels) for each one, which speeds up the process of scaling images.

The next step included using BlockMSG program, which allows to combine stereo pairs obtained using the Digitals/Delta digital station into a common photogrammetric network and to carry out its balancing by the communication method.

The algorithm for determining errors is based on the calculation of the coefficients of the third-degree polynomials. In such a way it approximates the systematic errors over the image field. The program uses polynomials of the following form:

$$\begin{cases} dx = a_1 \cdot 10^{-1} + a_2 \cdot 10^{-2} \cdot x + a_3 \cdot 10^{-2} \cdot y + a_4 \cdot 10^{-4} \cdot x^2 + \\ a_5 \cdot 10^{-4} \cdot y^2 + a_6 \cdot 10^{-4} \cdot x \cdot y + a_7 \cdot 10^{-6} \cdot x^2 \cdot y + \\ a_8 \cdot 10^{-6} \cdot x \cdot y^2 + a_9 \cdot 10^{-6} \cdot x^3 + 10^{-6} \cdot y^3; \\ dy = b_1 \cdot 10^{-1} + b_2 \cdot 10^{-2} \cdot x + b_3 \cdot 10^{-2} \cdot y + b_4 \cdot 10^{-4} \cdot x^2 + \\ b_5 \cdot 10^{-4} \cdot y^2 + b_6 \cdot 10^{-4} \cdot x \cdot y + b_7 \cdot 10^{-6} \cdot x^2 \cdot y + b_8 \cdot 10^{-6} \cdot \\ x \cdot y^2 + b_9 \cdot 10^{-6} \cdot x^3 + 10^{-6} \cdot y^3. \end{cases}, \quad (1)$$

where dx, dy – are the systematic errors, pixels; a_1, a_2, ..., a_9; b_1, b_2, ..., b_9 – are the parameters of the systematic errors.

The accuracy assessment of the obtained models is presented in Table 3 (minimum deviations are highlighted).

Table 3. Accuracy of normal and convergent survey methods (inclination angle α), with equal other parameters

f/α	Value of correction	Normal method				Convergent method			
		Average correction, µm	Mx, pixels	My, pixels	Mz, pixels	Average correction, µm	Mx, pixels	My, pixels	Mz, pixels
f = 200	average	393.1	0.727	0.777	0.654	1,086.7	0.841	0.816	0.466
35	max	774.8	1.072	1.524	–1.107	2,769.7	–2.479	–2.353	–1.604
f = 200	average	2098.3	2.116	3.325	2.473	1,263.3	1.201	1.628	0.907
30	max	6985.6	4.889	–11.693	5.242	2,361.2	3.082	–4.17	–1.918
f = 400	average	811.9	1.193	1.282	1.427	795.2	1.427	0.728	1.263
30	max	1,486.4	2.273	2.236	–2.771	1,980.1	4.604	1.225	3.801
f = 400	average	2,098.3	2.116	3.325	2.473	1,263.3	1.201	1.628	0.907
32	max	6985.6	4.889	–11.693	5.242	2,361.2	3.082	–4.17	–1.918
f = 700	average	1,098.4	1.728	1.78	2.646	1,130.6	1.955	1.477	1.803
20	max	1,952.7	3.467	2.734	–5.528	2,903.1	4.458	–2.584	3.799
f = 800	average	1,190.8	1.96	2.072	2.881	1,423.2	1.677	1.446	1.982
20	max	1,741.6	4.562	4.399	–6.06	3,823.3	3.324	3.343	–4.252
f = 800	average	1,742.9	4.959	5.51	7.339	1,862	3.259	3.902	6.825
27	max	2,704.3	14.211	–14.131	–20.33	3,103.8	–7.926	–9.494	15.42
f = 800	average	2,967.4	4.357	3.7	5.001	1,969.2	2.991	3.311	4.812

End of Table 3

f/α	Value of correction	Normal method				Convergent method			
		Average correction, μm	Mx, pixels	My, pixels	Mz, pixels	Average correction, μm	Mx, pixels	My, pixels	Mz, pixels
27	max	5,707.0	11.813	8.213	–12.00	3,481.6	–7.625	8.237	12.583
f = 800	average	2,558.7	1.813	3.531	3.198	2,396.1	3.233	2.201	2.491
20	max	4,473.5	3.666	10.306	5.051	3,487.1	7.798	–4.971	5.195
f = 1200	average	1,884.1	3.082	3.226	4.871	3808	4.881	4.682	5.327
30	max	2,968.2	–7.612	10.358	–8.402	11,198.5	–14.11	12.397	–10.951
f = 2000	average	3376	4.743	7.486	13.458	5,153.1	10.159	6.062	13.84
27	max	9,030.8	14.281	23.487	–36.08	12,839.	30.22	17.819	33.381
f = 1600	average	1332	2.132	1.367	6.878	1,230.5	2.099	2.809	3.28
20	max	2,159.2	5.41	3.883	–16.26	1,881.5	–4.27	6.088	7.151

Table 4 presents the total root mean square error of the horizontal and compilation network.

Analysis shows that the accuracy of the convergent method exceeds the accuracy of normal method (Table 4).

Table 4. The total root mean square error of the horizontal and compilation network

f/α	Correction value	Horizontal and vertical network	
		Mean square error of normal method	Mean square error of convergent method
f = 200	average	1.2490	1.2611
35	maximum	2.1673	3.7756
f = 200	average	4.6528	2.2171
30	maximum	13.7152	5.5287
f = 400	average	2.2590	2.0400
30	maximum	4.2243	6.0947
f = 400	average	4.6528	2.2171
32	maximum	13.7152	5.5287
f = 700	average	3.6271	3.0421
20	maximum	7.0749	6.4018
f = 800	average	4.0540	12.9718
20	maximum	8.7685	6.3486
f = 800	average	7.5950	6.5623
27	maximum	18.7376	16.8618
f = 800	average	5.0973	4.6370
27	maximum	12.0485	10.6070
f = 800	average	6.6055	8.6094
20	maximum	15.3566	21.7417
f = 1200	average	7.3295	4.8015
30	maximum	17.5680	10.3167
f = 2000	average	1.2490	1.2611
27	maximum	2.1673	3.7756
f = 1600	average	4.6528	2.2171
20	maximum	13.7152	5.5287

As can be seen from Table 4, in the range from *f* = 200 to *f* = 800, *f* = 1200 and *f* = 1600, the RMS of the convergent method is less than the RMS of the normal method, which indicates the advisability of using this method during practical work on the inventory and certification of real estate objects. Using data from Table 4, a histogram of the ratio of the RMS error for normal and convergent methods under equal conditions of use was visualized (Figure 8).

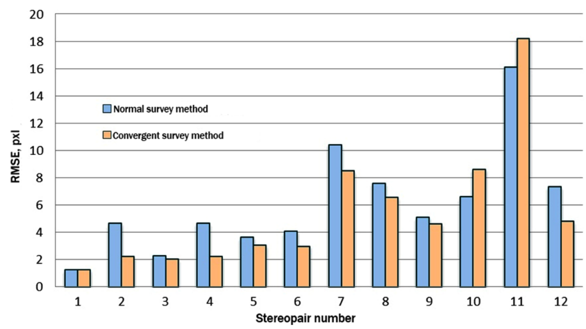


Figure 8. Distribution of the RMS in case of normal and convergent survey methods

To perform balancing in the program of analytical phototriangulation, it is necessary to use values of the coordinates of the reference points. To do this, it is necessary to generate a text file, in which four fields are indicated for each point: the point name (must coincide with the point name on the images), three spatial coordinates – X, Y, Z. Coordinate values are written to a text file with the extension * .dat or * .txt. A comparison of the results of the deviation at the reference points is presented in Table 5.

The RMS in the convergent method is significantly smaller (maximum value at Dz less than 2 cm) than RMS in the normal method. Comparison of RMS at reference and connecting points are presented in Table 6.

The effectiveness of normal and convergent survey methods can be estimated depending on a number of stations and the size of the datum sides. Before fieldwork, an approximate baseline value was calculated, because it

Table 5. Deviations at reference points

No	Normal method			Convergent method		
	Dx	Dy	Dz	Dx	Dy	Dz
1	0.024	–0.003	–0.02	0.021	–0.004	0.003
2	–0.034	0.012	–0.026	–0.032	0.007	–0.021
4	0.032	–0.001	–0.006	0.036	0	–0.014
5	–0.03	–0.008	0.055	–0.028	–0.002	0.034
Mean-square error	0.03	0.007	0.032	0.03	0.004	0.021
Maximum values	–0.034	0.012	0.055	0.036	0.007	0.034

Table 6. Comparison of root mean square errors at reference and connecting points

Point number	Normal method				Convergent method			
	Average correction µm	Mx	My	Mz	Average correction µm	Mx	My	Mz
1	59.80	0.024	–0.003	–0.020	51.2	0.021	–0.004	0.003
10	3.00	0.035	0.063	0.306	10.1	0.031	0.038	0.129
11	6.80	0.035	0.047	0.324	15	0.032	0.042	0.142
12	5.90	0.029	0.032	0.227	2.9	0.024	0.025	0.098
13	1.60	0.023	0.049	0.219	5.9	0.023	0.028	0.089
14	15.10	0.061	0.045	0.342	38.1	0.035	0.043	0.146
15	16.70	0.060	0.073	0.317	38.2	0.034	0.041	0.129
16	1.00	0.022	0.029	0.216	12	0.024	0.027	0.102
17	6.60	0.026	0.052	0.236	10.1	0.025	0.031	0.103
2	84.90	–0.034	0.012	–0.026	82	–0.032	0.007	–0.021
3	1.90	0.027	0.047	0.225	0.6	0.023	0.028	0.09
4	76.80	0.032	–0.001	–0.006	88	0.036	0	–0.014
5	53.50	–0.030	–0.008	0.055	62.2	–0.028	–0.002	0.034
The mean square values	39.40	0.04	0.04	0.23	43.4	0.029	0.029	0.097
The maximum values	84.90	0.06	0.07	0.34	88	0.036	0.043	0.146

may vary depending on the local terrain setting. To ensure the specified accuracy of determining the coordinates of the object points (m_x, m_y, m_z) it is necessary to calculate the basis of photographing B and distance S from camera to object. The value of the basis of photographing on the terrain B at the scale of the image b is calculated by the following formula:

$$B = \frac{Y_b}{f}, \tag{2}$$

where

$$b = \ell_x \cdot \frac{(100\% - P_x)}{100\%}, \tag{3}$$

where f – is the camera focal length value; b – is the basis of photography at the scale of the image; l_x – is the size of the image along the axis X; P_x – is the longitudinal overlap (%).

For 90% overlap, the baseline value was 6.8 m, while the work was performed, the baseline distance was 5.7 m. For the convergent surveying method, a formula, which consider the tilt of the camera is used:

$$B = 2 \cdot Z \cdot Tg\left(\frac{\beta}{2}\right), \tag{4}$$

where β – is an angle between optical axes of cameras; Z – is the distance from the centre of photographing to the object.

When the angle between the optical beams of the cameras is 1200, the baseline value is 10.8 m, and during the work, this value was 13.795 m. Under similar conditions (focal length, distance to the object of surveying, capture angle), when surveying a long building with the convergent survey method, 2 times fewer stations are used than when surveying this building with the normal method, and 2 times faster and more efficiently (Figure 9).

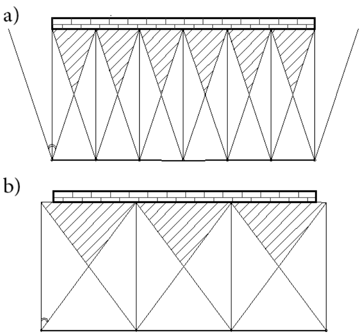


Figure 9. Comparison of the effectiveness of normal: a – and convergent; b – survey methods

Therefore, when performing the survey of the building by the convergent method, the accuracy of determining the coordinates is greater than when applying normal method. Therefore, with the same parameters and conditions of survey for the inventory and certification of religious buildings, it is recommended to use of a convergent method of survey. The obtained results show that with the complete overlapping of images, the focal length does not affect the increase in the accuracy of using one or another method of a survey of the architectural structures. With a short shooting distances of up to 10 m, it is possible to obtain a centimetre accuracy. However, the cost of such work will depend only on the time spent and the qualifications of the performers.

Features of the digital non-metric cameras do not allow to use the known mathematical models of previous calculation of accuracy and shooting parameters. In case of monitoring architectural monuments, the issue of accuracy and optimal design of works is of particular importance, since quite often the survey has to be carried out in cramped conditions, and the survey geometry is characterized by the presence of extreme values of the external orientation elements (angles).

To overcome the abovementioned problems, we determined the main scientific and practical tasks in the study, which include to improve existing technologies, mathematical models and methods for monitoring architectural monuments using recent achievements of digital photogrammetry, in particular the capabilities of modern digital non-metric cameras. The performed study demonstrated that the accuracy of the convergent method is almost 2 times higher than the accuracy of the normal photogrammetric survey method. Besides, it provides a large survey overlap in the study area. Comparing all the indicators and characteristics of both methods, we concluded the feasibility, high profitability and low complexity of the convergent method of stereo photography to perform the inventory and certification of the real estate.

The obtained accuracy of determining the coordinates of the building meets the requirements for the accuracy of measurements of architectural monuments. The use of terrestrial laser scanning, scanning with hand-held laser scanners and shooting with light and ultralight UAVs are relevant and highly cost-effective, which reduces the geometric characteristics of architectural monuments dozens of times cheaper than traditional geodetic methods.

It is proved that the set of points obtained by using laser scanning gives the possibility to detect the errors connected with survey, to learn and consider the distortion of the made images (distortion, error, orientation components, etc.). The accuracy of the set coordinates of the construction meets the demands of accurate measurements of architectural monuments.

Conclusions

The convergent method of model construction has clear advantage in terms of ease of measurement, as the original data is stored in the computer memory. Therefore, in case of error, it enables to avoid repeated field measurements, fieldwork becomes less time-consuming, data processing is relatively fast. Generating of the model images was performed to assess the accuracy of normal and convergent survey methods with set parameters. The accuracy of obtaining the coordinates by normal method is higher in comparison with the convergent method. However, to solve a number of practical problems, the obtained accuracy fully satisfies the needs and requirements. The accuracy of the data obtained as a result of a real experiment during the stereo photography of the facade of the cult building was evaluated. The analysis of the performed calculations proved that the application of the convergent method provides a larger area of overlap of the survey and allows to obtain smaller values of the root mean square errors. However, despite the results obtained, some questions remain unsolved and recommended to be a focus in future studies. These include further automation of geodetic measurements, the search for new optimised mathematical models for correction of image distortions, and integrating survey data with other data sources, such as ground laser scanning, scanning with hand-held laser scanners, and shooting from light and ultralight UAVs, to mention a few.

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