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DIGITAL PHOTOGRAMMETRY FOR BUILDING MEASUREMENTS AND REVERSE-ENGINEERING

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Abstract. Architectural photogrammetry is a technique to acquire three dimensional (volumetric) or two dimensional geometric data of buildings for a CAD model from their images. Usually photogrammetric methods (together with the laser scanning) are being implemented for the complex surfaces the measurement of which by any other means is extremely complicated. However, regular geometric forms can also be measured using this method. This is especially an issue in case of possible comparison of the results obtained by different means. In this paper the photogrammetric measurements of geometric elements of the building, with the comparison and evaluation of quality of the results are presented.

Keywords: digital images, photogrammetry, 2D model, measurements comparison.

1. Introduction

For many purposes geometric information about existing buildings or the ones under construction in 2D plans or three dimensional CAD models is necessary for control, conservation or reconstruction. If the data are still available from the construction process, they may have insufficient actuality. In a modern environment the 3D CAD data are preferred, showing the actual state of the building. These data may be acquired by a manual measurement using geodetic survey instruments, by theodolites or tachometers, or by photogrammetry using digital images (Luhman, Tecklenberg 2001; Sužiedelytė Visockienė 2007).

The project of the building under construction dimensions control is described further in this paper. Since for a higher precision the measurements were performed using 2 methods (these are measurement by photogrammetric principles and the measurements by the laser distance-meter) it was possible to compare these two principles determine the accuracy achieved.

Fig. 1. Image of the measured building with some of the marks shown

2. Determination of the construction site dimensions

The primary objective of the investigation was to determine the actual dimensions of windows of the building under construction (Fig. 1). For that purpose it was decided to implement the photogrammetric methods, namely use the PhotoMod photogrammetric software (Boroumand, Doost 2006; Serebryakov, Nepeina 2006).

For receiving the unambiguous tie points of images for further processing and obtaining the scale factor a large number of marks were placed all over the building (marked as white circles in Fig. 1). The precise 3D position of each mark was determined using the digital tacheometer and those data were transferred to the photogrammetric PhotoMod project. Dimensions and the position of the windows were determined inside the mentioned project.

The processing of images in the photogrammetric project with the dimensions evaluation is described in the further chapters of this paper.

3. Building reconstruction using photogrammetric method

In photogrammetry we usually measure the 2D image coordinates of points in 2 or more images and calculate the 3D coordinates in a superior coordinate system. The coordinates of each point in the images are usually determined by a special high precision (and expensive) photogrammetric instrument, like PlaniComp P2 (Leica) in the classical photogrammetry. In digital photogrammetry this is done on screen of PC using the **pixel coordinate** system defined by rows and columns. If analogue image sources are to be used, they must be scanned by an image scanner. The image acquisition and processing are shown in Fig. 2 (Boroumand, Doost 2006).

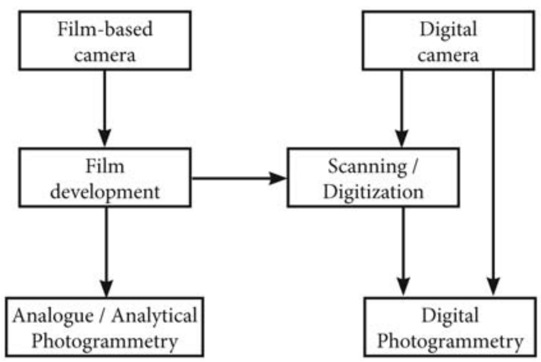

Fig. 2. Image acquisition and image processing in photogrammetry

The first part of the photogrammetric process is the **acquisition of the images** with analogue photographic (UMK camera) or digital cameras. The analogue imaging devices can be metric, semi-metric or amateur cameras. During the last years some digital cameras have been developed using a CCD (Charge-Couple-Device) sensors (arrays). But whereas the low budget cameras have an insufficient resolution, cameras with larger CCD arrays are still expensive. But a development towards cheaper and better digital cameras can be anticipated in the near future. This will allow a fast digital data flow, avoiding the time consuming wet photographic processes.

Each point, which is required for the complete restitution of the object, has to be displayed on at least 2 images from different points of view. If it is desired to view the object in a stereoscopic manner, the images have to be taken according to the so called *normal case of photogrammetry* with nearly parallel directions of view from two points on a horizontal base, perpendicular to the viewing directions. Such an arrangement is similar to the arrangement of the human eyes.

If the pictures are acquired especially for photogrammetric purposes, the imaging team will survey a **few control points by geodetic techniques** (Skeivalas 2008). Control points are points with 3D coordinates in a geodetic coordinate system, which can be identified and measured in at least one image. They are necessary for the orientation to follow, which is the second step of the photogrammetric process.

The orientation procedure consists of the reconstruction of the **interior orientation**, which describes the geometry of the ray beam in the camera and the exterior orientation.

The interior orientation is needed for the calculation of parameters determining the position of coordinate system of image and orientation regarding the coordinate system of the digital view.

If the camera with the known camera calibration parameters is used, the transformation of image to the geodesy coordinate system is calculated according to the equation (Software PhotoMod 4.4 AT):

$$\begin{aligned} x &= x_c^{'} + k_x \left(x_c \cos\varphi - y_c \sin\varphi \right), \\ y &= y_c^{'} + k_y \left(x_c \sin\varphi + y_c \cos\varphi \right), \end{aligned} \tag{1}$$

where x, y – coordinates of a point in the geodesy coordinate system; x_c, y_c – coordinates of the points in digital image coordinate system; x_c' y_c' – null-point of the digital image coordinate system in the geodesy coordinate system; φ – the rotation angle of the image coordinate system in the geodesy coordinate system; k_c, k_c – the coefficients describing an image deformations along the x, y axes.

The interior orientation can be performed in automated or manual mode using the special PC softwares (Software PhotoMod 4.4 AT).

If the used camera is calibrated, interior image orientation may be done by transforming the measured coordinates into a calibration system, defined by fiducial marks or residual crosses.

If a non-calibrated camera has been used, an independent set of parameters of the interior orientation is necessary for each image. In frame cameras independent parameters of the interior orientation are only required if the zoom factor or the focus of the camera has been changed during the image acquisition.

The **exterior orientation** describes the position and the viewing direction of the camera in a superior object coordinate system and is today usually calculated by a bundle adjustment. This is the simultaneous calculation of the data of the exterior orientation, the data of interior orientation (if required) and the 3D coordinates of the points, of which 2 or more pairs of image coordinates are available. For this purpose at least three control points and 5–10 tie points per image are required. Tie points have to be identified and measured in at least 2 images. For each image at least 6 unknowns (3 coordinates for the position, 3 rotations and if required parameters of the interior orientation) and for each object point 3 coordinates have to be estimated. The unknowns can be calculated by a least squares adjustment if more observations than unknowns are available. The more control and tie points are available, the better results of the orientation process in terms of accuracy and reliability can be obtained.

4. Practical measurements

As was mentioned before, the main task of the work was to measure the dimensions of the windows of the building being under construction (Fig. 1). The marks placed on the outer walls of the building were used for both exterior and interior orientation of the images taken by the *Canon EOS 350D* digital camera, and the exact coordinates of the points (marks) were determined using *Leica* total station (ISO 5725-1:1994).

The original images were digitally corrected by the TCC software (developed by the Photogrammetric Institute of University of Bonn), according to the camera calibration results (Sužiedelytė-Visockienė 2007). To obtain the needed measures, the images were processed using the PhotoMod photogrammetric software. Since only the actual dimensions of the windows were required, only the measurements of the areas of interest were performed. The results of windows dimensions measurements (of a certain small area of the building) are shown in Table and graphically (with their actual positions) in Fig. 3. As can be seen from the figure, it was possible to measure only limited number of the windows – those which were clearly visible, the windows at the bottom floors were covered by the scaffolds and it was impossible to perform measuring due to the lack of the visual contact with the areas to be measured.

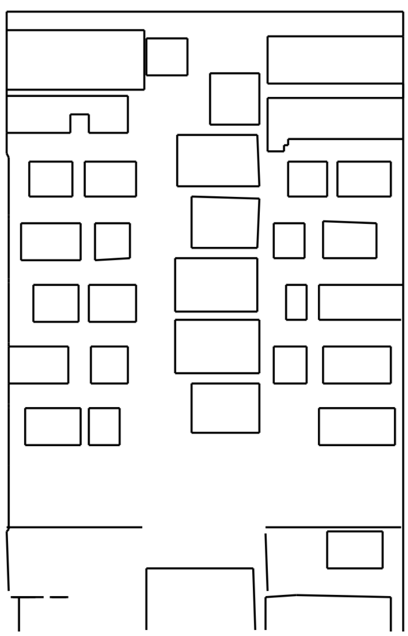

Fig. 3. 2D drawing of the constructed building accomplished by means of photogrammetry

Since the digital images of the object (building) used for measuring were taken at quite large distances and those were impossible (or extremely difficult) to decrease, the accuracy of measurements based on the measurements of pixels position in images was also quite limited. Due to that, to obtain some additional data on the measures and the photogrammetric measurements themselves it was decided to perform additional measurements of windows dimensions using the instrument of a higher and well-known accuracy. The instrument used was the laser distance-meter *Leica Disto TM Plus, having the standard deviation of measurements* s_d = 1,5 mm. The windows of the entire building were measured using the mentioned instrument at several positions (Fig. 4). The results of windows dimensions measurements performed by the laser distance-meter are shown in Table 1.

Considering the measures obtained by *Distomat* as being the reference ones (since the accuracy was known and it did not change through the entire measurement process), it was possible to compare and calculate the deviations of measures obtained by means of photogrammetry. The deviation of the photogrammetric measurements:

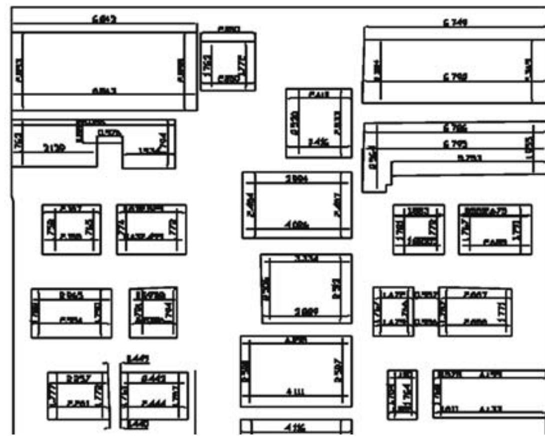

Fig. 4. Fragment of the windows dimensions determined by *Leica Disto TM Plus*

$$d\Delta_{ph} = \Delta_{ph} - \Delta_d, \quad (2)$$

where Δ_{ph} – measures obtained by means of photogrammetry; Δ_d – reference measures obtained by laser distance-meter.

The calculated deviations for each floor are shown in Table 1 and in Fig. 5.

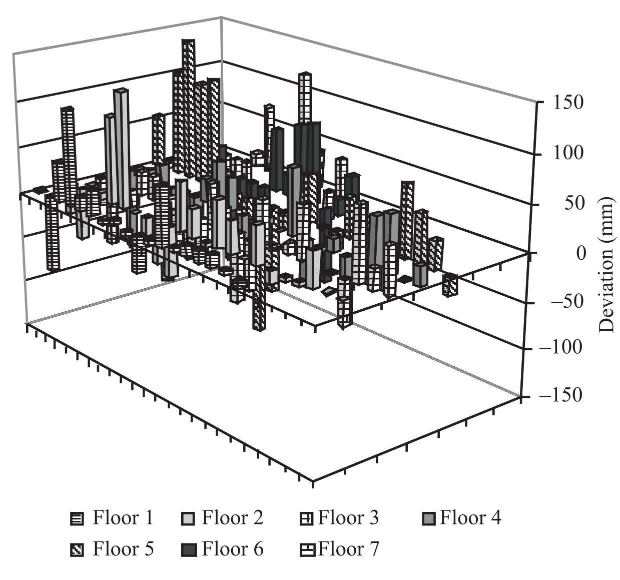

Fig. 5. Scatter of the deviations of dimensions according to the floor of the building

Having the deviations of photogrammetric measurements calculated the standard deviations of mentioned measurements for each floor of the building could be found (ISO 17123-1:2002):

$$S_{ph} = \sqrt{\frac{1}{n-1}\sum_{k=1}^{n} d\Delta_{phn}^2}, \quad (3)$$

Table 1. Measures of the windows taken by different methods with the deviations

Floor 1			Floor 2			Floor 3			Floor 4			Floor 5			Floor 6			Floor 7		
Distomat (mm)	Photogrammetry (mm)	Deviation (mm)	Distomat (mm)	Photogrammetry (mm)	Deviation (mm)	Distomat (mm)	Photogrammetry (mm)	Deviation (mm)	Distomat (mm)	Photogrammetry (mm)	Deviation (mm)	Distomat (mm)	Photogrammetry (mm)	Deviation (mm)	Distomat (mm)	Photogrammetry (mm)	Deviation (mm)	Distomat (mm)	Photogrammetry (mm)	Deviation (mm)
3367	3371	4	4116	4084	−32	4095	4064	−31	3334	3247	−87	3994	4050	56	2410	2480	70	6843	6756	−87
3385	3304	−81	4137	4082	−55	4111	4043	−68	3289	3296	7	4026	4035	9	2416	2424	8	6843	6767	−76
2508	2551	43	2575	2585	10	2580	2590	10	2506	2516	10	2454	2566	112	2530	2498	−32	2893	2826	−67
2510	2613	103	2567	2574	7	2597	2580	−17	2513	2533	20	2457	2607	150	2533	2559	26	2898	2846	−52
2686	2702	16	2985	3078	93	2257	2284	27	2965	2957	−8	2167	2274	107	6056	5957	−99	2050	2066	16
2679	2707	28	2986	3110	124	2261	2288	27	2954	2951	−3	2155	2270	115	3139	3105	−34	2050	2122	72
1789	1784	−5	1817	1817	0	1777	1693	−84	1782	1761	−21	1758	1778	20	976	921	−55	1763	1750	−13
1789	1797	8	1815	1796	−19	1772	1723	−49	1790	1816	26	1765	1754	−11	1934	1882	−52	1779	1761	−18
411	403	−8	1166	1121	−45	449	401	−48	697	745	48	615	530	−85	1763	1830	67	6749	6869	120
425	387	−38	1168	1115	−53	440	406	−34	704	740	36	631	489	−142	1794	1818	24	6792	6833	41
1579	1576	−3	1846	1899	53	2443	2487	44	1738	1695	−43	2529	2438	−91	6786	6868	82	2324	2292	−32
1566	1628	62	1844	1875	31	2444	2465	21	1736	1700	−36	2499	2480	−19	6795	6882	87	2349	2390	41
1782	1788	6	1819	1814	−5	1763	1692	−71	1791	1799	8	1774	1800	26	5753	5673	−80			
1773	1786	13	1652	1702	50	1757	1703	−54	1794	1794	0	1772	1822	50	2564	2580	16			
3781	3794	13	1664	1697	33	1100	1146	46	1472	1543	71	1883	1881	−2	1955	2001	46			
3776	3790	14	1784	1785	1	1085	1089	4	1479	1432	−47	1883	1865	−18						
1790	1794	4	1786	1826	40	1764	1776	12	1767	1761	−6	1781	1823	42						
1806	1797	−9	824	810	−14	1764	1820	56	1766	1779	13	1772	1798	26						
			811	805	−6	578	569	−9	957	923	−34	555	556	1						
			3367	3362	−5	611	609	−2	956	968	12	555	575	20						
			3363	3399	36	4199	4151	−48	2667	2721	54	2675	2750	75						
			1798	1800	2	4133	4211	78	2656	2717	61	2685	2737	52						
			1788	1788	0	1768	1790	22	1787	1784	−3	1767	1796	29						
						1762	1811	49	1771	1791	20	1791	1772	−19						
St. deviation 39.25			St. deviation 44.70			St. deviation 45.42			St. deviation 37.25			St. deviation 70.82			St. deviation 60.64			St. deviation 64.14		
Average distance from camera to object (m)																				
30.064			31.037			32.289			33.725			35.367			37.214			38.876		

where n – number of measurements; $d\Delta_{phn}$ – deviation of each measure.

Standard deviations for each floor are listed in Table 1 and graphically shown in Fig. 6.

From Fig. 6 it is clearly visible that the standard deviation of measurements depends on the floor of the building, i.e. it depends on the distance from the camera to the measured object. The higher the floor of the building (larger distance), the bigger standard deviation of photogrammetric measurements appears. The dependency of the standard deviation of photogrammetric measurements upon the distance to the measured object is graphically shown in Fig. 7.

As it can be seen from Fig. 7 the dependency of the standard deviation of measurements on the distance is

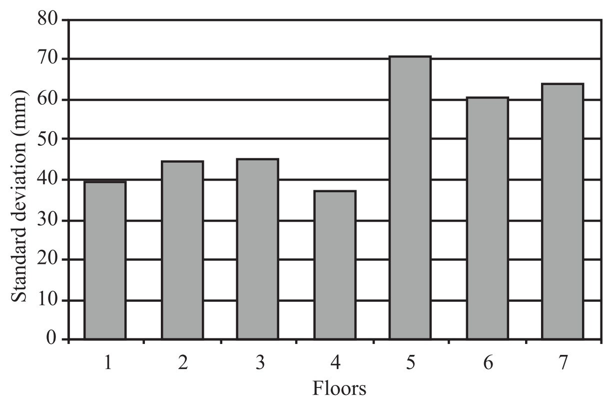

Fig. 6. Standard deviations of the photogrammetric measurements at each floor of the building

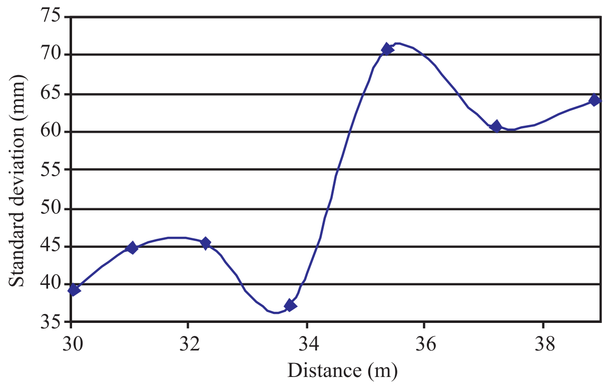

Fig. 7. Standard deviations of the photogrammetric measurements at each floor of the building

almost linear despite some obvious faults falling out of the more or less linear shape.

Overall standard deviation of measurements including the standard deviation of reference measures (laser distance-meter) can be calculated (ISO 5725-1:1994):

$$S_{phf} = \sqrt{S_{ph}^2 + S_d^2}. \tag{4}$$

The calculated full standard deviation of measurements is S_{phf} = 51.03 mm.

5. Conclusions

1. Photogrammetric methods can be implemented in the reverse-engineering of buildings (for heritage reconstruction or dimension control) quite successfully allowing obtaining the needed dimensions from the images long after the conditions of object has changed.
2. Photogrammetric method of dimension evaluation produces quite large errors of measurement heavily depending on the distance to the measured object and the resolution of camera.
3. Depending on the distance to the measured object, standard deviations of measurement in project described varied from 39 mm (at 30 m) to 64 mm (at 39 m).
4. General standard deviation of 9-floor building measurements was estimated as 51 mm, which is not quite acceptable in many cases.
5. Despite the accuracy of not high enough (at large distances), the photogrammetric object measurements allow estimating not only the dimensions of the object itself but also its position (coordinates), which is sometimes quite difficult to accomplish by other means of measurement.

References

Boroumand, M.; Doost, N. 2006. Report on Processing Digital Images Taken by UltraCam In PHOTOMOD Version 4.0, in *VI International PHOTOMOD User Conference*, Becici, Budva, Montenegro. 46 p.

Skeivalas, J. 2008. *GPS tinklų teorija ir praktika* [Theory and practice of *GPS* networks]. Vilnius: Technika. 288 p.

ISO 17123-1:2002 Optics and optical instruments – Field procedures for testing geodetic and surveying instruments – Part 1: Theory. Geneva: ISO. 10 p.

ISO 5725-1:1994 (Trueness and Precision) of Measurement Methods and Results – Part 1: General Principles and Definitions. Geneva: ISO. 22 p.

Leica DISTO. Available from Internet: <http://www.leica-geosystems.com>.

Luhman, T.; Tecklenberg, W. 2001. *Hibride photogrammetric and geodetic surveillance of historical building for urban tunnel construction*. Available from Internet: <http://www.fh-oow.de/institute/iapg/paper/ Tunnel%20Hemelingen.pdf>.

Serebryakov, S. V.; Nepeina, N. N. 2006. Practical experience of digital topographic mapping and orthophotos creation using PHOTOMOD software system, in *VI International PHOTOMOD User Conference*, Becici, Budva, Montenegro, September 19–22, 15.

Sužiedelytė-Visockienė, J. 2007. Skaitmeninės matuojamosios fotokameros kalibravimo parametrų įtaka nuotraukas transformuojant į plokštumą [Definisions influence for Digital Photocamera parameters of calibration on transformation of photos in the plane], *Geodezija ir kartografija* [Geodesy and Cartography] 33(1): 26–30.

Software PhotoMod 4.4 module Aerial Triangulation user manual. Racurs, Moscow. Available from Internet: <http://www2.racurs.ru/docs/en/at.pdf>.

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