661. Influence of photogrammetric dynamic movements of non-metric camera on the accuracy results in digital images processing

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Abstract. Real-time photogrammetry is used for the registration and control of object structure and deformations, registration of dynamic processes, particularly, in the architectural heritage objects. The main product of the photogrammetry is a three-dimensional (3D) data – real world vision at the time the images are acquired with fixed viewing angles. In order to achieve this result a lot of digital photogrammetric workstations (DPW) were designed. A wide range of digital imagery such as scanned aerial film frames, images from digital aerial cameras as well as images from various satellite sensors could be processed using DPW. The requirements of processing, the algorithms of the photogrammetric software systems for the dynamic line-by-line acquisition processing of digital images in the photogrammetric way differ according to the applications. Therefore, it is important to test the capabilities and data accuracy of more than one digital photogrammetric system. The images of the research object were taken by a digital non-metric camera *Canon EOS 1D Mark III*. The quality of images depends on the camera optical system errors (calibration parameters) and camera stability - dynamic movements during images exposure. Thus, it is necessary to test calibration results and camera positions during the image exposure time. In this case, the camera was recalibrated and the new calibration parameters were checked during the images processing. Values that define camera stability and dynamics were determined. Close-range digital images were processed – the triangulation procedure was accomplished by using digital photogrammetric software PhotoMod and *Inpho* as well as DPW system *Bluh*. The accuracy of triangulation has been tested and compared with the manufacturer's software.

Keywords: digital camera, calibration parameters, triangulation, standard deviation, dynamic processes.

1. Introduction

Photogrammetric software system is developed in such a way that the measurements of the image coordinates can be used as the input for the bundle block adjustment, the measurement of digital stereo pairs, the Digital Elevation Model (*DEM*) generation by automatic image matching, the filtering of elements not belonging to *DEM*, the orthophoto generation, including the mosaics of orthophoto and the processing of *DEM*. The processing of *DEM* includes the computation of break lines, *3D* representation and more. The whole program system is computer-based and easy to handle. Thus, today when using very little effort, the whole world of photogrammetry is available on standard PCs [1]. The basic requirement of the photogrammetric software systems for the processing of digital data is application-dependent. In this article the test of digital images processing was performed by using digital photogrammetric systems (*PhotoMod* and *Inpho*), which are suitable for aerial photogrammetry works and with the bundle triangulation program *Bluh*. The images were taken with a digital non-metric calibrated camera. Digital camera calibration procedure and comparison between the old calibration results and between the new one are provided in this article. The digital camera is on the move during the images exposure time. The camera movement is a photogrammetric dynamic process, which influences the quality of the images. These discrepancies between the movements of two cameras have a position error – an x-parallax error, which is observed in the image during processing – ground control points (*GCP*) and tie points measurement time. The mathematical aspect of a relative movement between the static objects and between the imaging systems is presented.

2. Accuracy control of photogrammetric work stages

Digital image processing with photogrammetric software consists of the relative orientation (measurements of *GCP* and tie points) and calculation of triangulation (processing procedure). Accurate measurements of the points lead to the accurate results of triangulation (bundle adjustment). Thus, the measurement quality should be observed at every work step [2, 3]:

1) Accuracy control using correlation coefficient. The acceptable value of the correlation coefficient can be determined from the quality of the images. For contrast and high quality images the threshold is 0.9–0.95, for unclear images the threshold can be 0.8 at well recognized points. The unclear images are when the camera is not stable during image acquisition.

2) Accuracy control using vertical parallax residual. After measuring the points on the stereo pair, the relative orientation parameters of images are calculated and then recomputed more exactly by software while the points being added. The photogrammetric program calculates the maximum error of vertical parallax residuals ($E_{\max}$) and the root mean squared error (*RMS*) [3]:

$$E_{\max} = 2 \times E_{mean} , \tag{1}$$

$$RMS = \sqrt{2} \times E_{mean} , \tag{2}$$

where E_{mean} – is a mean error of measurement points on the stereo pair.

This E_{mean} error should not be greater than half of the scanning pixel size for the analogue camera and half of matrix pixel size for digital camera.

The analyzed images have been taken with digital camera *Canon EOS 1D Mark III* with the matrix pixel size of 6.4 µm. Thus, the mean value (E_{mean}) should not be more than 3.2 µm. The maximum error ($E_{\max}$) and the *RMS* of measured tie and *GCP* with our camera should not exceed the calculated values given in Table 1.

Table 1. Calculated maximum error and *RMS* error for the digital camera *Canon EOS 1D Mark III*

Maximum error, µm				
$E_{\max}$	*RMS xy*	*RMS z*	$E_{xy(mean)}$	$E_{z(mean)}$
6.4	4.5	4.5	4.5	17.0

3) Accuracy control by adjacent models (in overlapping or triplets). After measuring the tie and *GCP* on the stereo pairs (models) the data should be transferred to the geodetic coordinate system. The relative orientation accuracy can be checked by comparing the discrepancies of the points measurements on the adjacent models (in triplets). Triplet errors: E_x, E_y, E_z in their *X, Y, Z* coordinates were calculated on two adjacent models. Mean triplet errors in *xy* plane and *z* coordinates are calculated with the following formulas [3]:

$$E_{xy(mean)} = \sqrt{2} \times 0.5 \times pxl , \tag{3}$$

$$E_{z(mean)} = \frac{c}{b_x} E_{xy(mean)} , \tag{4}$$

where *pxl* – is the matrix pixel size for a digital camera (6.4 µm); *c* – is the focal length of a camera (51 mm); b_x is a photographic base in the image scale.

Figure 1 illustrates the accuracy potential of the typical imaging and processing systems as well as common and optimal system combinations [4].

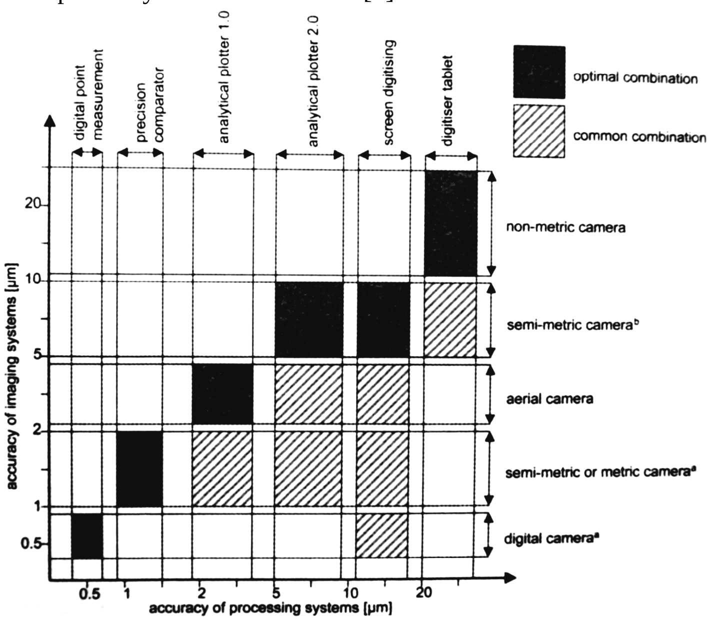

Fig. 1. Accuracy potential of imaging and analysis systems

Digital imaging systems can reach image measurement accuracies of 0,2 – 1 µm (1/10 – 1/50 pixel) depending on the mechanical stability of the camera (Fig. 1). The value of the standard deviation of the unit weight (σ_0) indicates the final accuracy of the aerial triangulation.

In general, the higher image resolution, the better image quality is obtained, providing better accuracies of the photogrammetric processes. The quality of images depends on the optical system errors (camera calibration parameters), the characteristics of the camera and photogrammetry dynamics – relative movements between the static objects and the camera occurring in a hand-held photography. It is necessary to make camera calibration and test the old calibration parameters as well as control image sequences.

3. The purpose of camera calibration

The purpose of camera calibration is to determine the geometric camera model described by the parameters of the interior orientation [4, 5]:

- principal distance;
- focal length (*c*) of the camera;
- image coordinates of principal points;
- radial distortion;
- tangential (asymmetric or symmetric) distortion;
- affinity and shear of the image coordinate system;
- other additional parameters.

There are 3 different camera calibration methods characterized by the reference object used and by the time and location of calibration [5]:

• Laboratory calibration. Interior orientation parameters are determined by goniometry, collimators or other optical alignment techniques where the imaging direction or the angles of light rays are measured through the lens of the camera. The advantage of this method is that the

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calibration takes place under laboratory conditions and hence better accuracy at defining of unknown quantities is achieved. Laboratory calibration is generally used only for the metric cameras and before surveying.

- Test field calibration. This type of calibration is based on a suitable targeted field of the object points with the known coordinates and distances. The images of a test-field are taken from different positions and directions from several camera stations (the number of camera stations depends on the test field size), ensuring good ray intersection and filling the image format. The neighboring images should be overlapped. The measured image coordinates and approximately known object data are processed by bundle adjustment in order to give the parameters of the camera model (interior orientation) as well as the adjusted test field coordinates as well as the parameters of the exterior orientation. Test fields can be mobile, or stationary.
- Self-calibration. For this type of calibration the images acquired for the actual object measurement are used. In this case the test field is replaced by the actual object, which must be imaged under conditions similar to those required for the test field calibration itself (spatial depth, tiled images and suitable ray intersections). Self-calibrations do not require coordinates of the known reference points. The parameters of the interior orientation can be calculated solely by the photogrammetric determination of the object shape. If employed, reference points can be used to define a particular global coordinate system for the parameters of exterior orientation.

Camera calibration procedure can be divided into several stages: test-field target image acquisition, processing of the resulting images and estimation of camera parameters [6]. Determination of parameters of the cameras (camera calibration) is absolutely necessary for the successful images processing. Camera *Canon EOS 1D Mark III* calibration results are presented in chapter 5.

4. Relative movement between imagining objects and imaging system

Stationary object can be recorded off-line by sequential imaging with only one digital calibrated camera. The movement of a camera during the exposure time causes an image blur $\Delta s'$. The image blur depends on the velocity, exposure time and image scale [4]:

$$\Delta s' = \frac{\Delta t \times v}{m} = \frac{\Delta S}{m}, \tag{5}$$

where Δt – exposure time; v – velocity of a camera movement; m – image scale factor; ΔS – a distance moved.

Blurring motion results in a decreased modulation transfer in the direction of the movement. The maximum analyzed cameras (*Canon EOS 1D Mark III*) blur ($\Delta s'$), when Δt =1/8000s, v =1.5 m/s and image scale factor 1/50 (close-range photogrammetry) is 9 µm or 1.4 pixel in images. The camera position error (x-parallax error) is visible in the image during the processing when *GCP* and tie points are measured in the images by stereo mode. The standard case of the stereo photogrammetry is presented in Fig. 2.

Movement ΔS between time t_0 and between t_1 results in the measurement of the virtual points P^* corresponding error ΔZ in the viewing direction is given by the expression:

$$\Delta Z = \frac{h}{b}\Delta S = \frac{h}{b} m \times \Delta px', \tag{6}$$

where h – object distance; b – stereo base; $\Delta px'$ – x-parallax error and $\Delta px' = \Delta s'$; m – image scale factor.

In the direction of the movement the lateral error ΔX is the following:

$$\Delta X = \frac{x'}{c}\Delta Z \,, \tag{7}$$

where x' – point P^* coordinate in the left image; c – principle distance (focal length of camera Table 3).

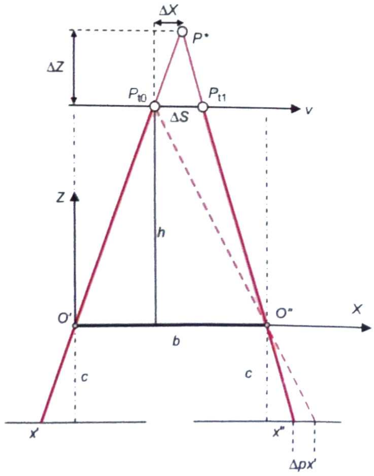


Fig. 2. Standard case of stereo photogrammetry

If h =20 m, b =2 m, ΔS =0.00018 m (from formula (5)) error in the viewing direction ΔZ =1.8 µm or 0.3 pixel in images. Also if x' =4 mm, c = 50 mm (analyzed by *Canon EOS 1D Mark III*) error in the direction of the movement is ΔX =0.14 µm or 0.2 pixel in images. The example demonstrates the effect of the synchronization error on the quality of the points coordinates in the object. The lateral image error of 9 µm exceeds the potential image measurement accuracy of < 1 µm (Fig. 1) by almost an order of magnitude. Therefore, it is very important to control the stability and dynamic movements of a camera during exposure.

5. Result of calibration of *Canon EOS 1D Mark III*

The non-metric camera *Canon EOS 1D Mark III* was calibrated (its optics distortions determined and evaluated) by using *Tcc* software at the Institute of Photogrammetry of University of Bonn (Germany) in 2008 [6]. The camera parameters are used in the practical work now. The camera was recalibrated in the Photogrammetric laboratory at the Neubrandenburg University (Germany) using 3D test-field after three years (Fig. 3).

The field consists of the retro reflective targets with the known coordinates and distances and of two calibrated scale bars with the precisely known distance between the points. In order to get spatial information some points are arranged on a stamp at the top of the plane [7]. In order to capture all types of distortions and stabilize the determination of the focal length (especially when using longer focal lengths) the images were taken:

- In different orientations. At each station, the camera was rotated around its optical axis by 0º, 90º and –90º ;
- In different inclinations.

The camera position with the used different orientations and inclinations is given in Fig. 4.

185 images were used for the successful processing of the calibration. The images were processed and computations of the camera calibration parameters were made by using analyzed digital photogrammetric software *AICON 3D Studio* [8, 9]. In order to evaluate the differences

between the calibration parameters and to estimate the necessity of using the scale bars, the images were processed in two different ways:

- including scale bars for the images processing;
- excluding scales bars in the images processing.

Fig. 3. Test-field for the camera calibration

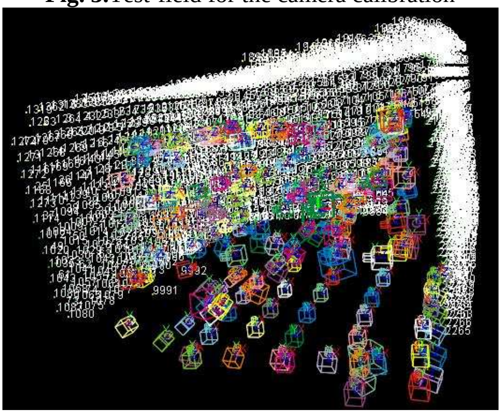


Fig. 4. Photo camera position

During the adjustment procedure the software created an approximate 3D model of the points marked on the test-field. The coordinates are required to number the retro reflective targets (including the scale bars), that are detected in the image and to set up correspondences between the targets in different images. The accuracy of the results is defined by the mean value in the coordinate list for X, Y, Z; *RMS* and the standard deviation of the weight unit (σ_0). Standard deviation indicates mean point measurement accuracy for all the images of the adjustment. The results of calibration are listed in Table 2.

Table 2. The accuracy results of bundle block adjustment for camera calibration

Accuracy, μm	Calibration with scale bars	Calibration without scale bars
$E_{xy(mean)}$	4.5	3.2
$E_{z(mean)}$	2.5	2.1
RMS XY	5.0	4.0
RMS Z	3.4	3.1
σ_0	5	5

According the estimated σ_0 value it could be stated that the results of camera calibration in both ways are excellent [10]. Interior orientation and objective optic distortion parameters of the camera, i.e. principal distance *c*, principal point offset x_0/y_0, radial-symmetric and tangential distortion coefficients were calculated simultaneously with the numerical 3D reconstruction process by bundle adjustment. The old and new calibration results of the digital camera are provided in Table 3.

Table 3. *Canon EOS 1D Mark III* recalibration results obtained with *Tcc* and *AICON* software packages

Parameters	Results		
	The old calibration by Tcc (2008 year)	The new calibration by AICON (2011year)	
		With scale bars	Without scale bars
Objective focal length (mm)			
c	50.7583	50.7930	50.7931
The base point corrections of the photo-camera (mm)			
x_0	-0.0495	-0.2282	-0.2324
y_0	-0.2559	0.2019	0.2026
Radial-symmetric distortion of the photo-camera			
A1	–1.789E-09	-6.4466E-05	-6.4508E-05
A2	-	4.1312E-08	4.1565E-08
A3	-	2.8812E-11	2.8407E-11
Radial-asymmetric distortion of the photo-camera			
B1	1.0170E-05	-7.1262E-05	-7.2810E-06
B2	–1.655E-8	-2.5987E-06	-2.5725E-06
Affinity/Orthogonality			
C1	-	1.3696E-03	1.3715E-03
C2	-	-2.5531E-05	-2.6262E-05

The values between old camera calibration parameters and the new ones are very different. However, the differences between the proportion of the obtained values of calibration parameters and between the amount of the computed calibration parameters in both cases (in old calibration and in new calibration) do not mean bad result, because the computations of the parameters were performed by using different software and different technique during the image acquisition process. Also, there are no standards for calibration reports of the digital cameras at the moment. In this case, the camera calibration parameters, which should be entered during the project creation process depends on the software which is used for the images processing. Camera calibration parameters which were entered into the digital photogrammetric software (*PhotoMod* and *Inpho)* and system *Bluh* is not the same. The old camera calibration parameters are used for the processing of images by *PhotoMod* software. New camera calibration parameters are used processing images by *Inpho* and *Bluh*.

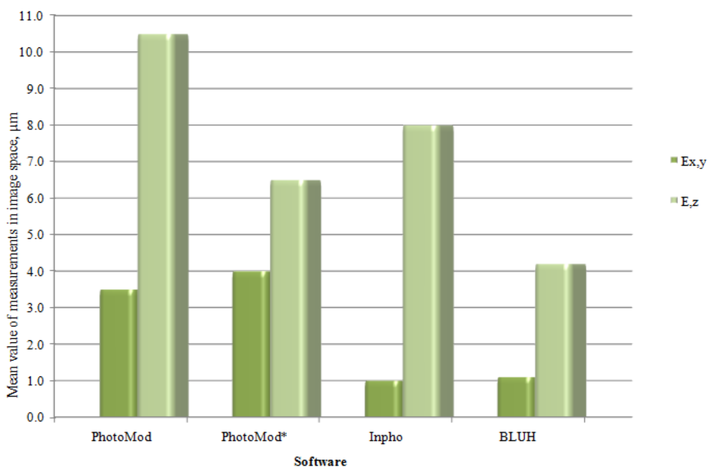
6. The analysis of results for the processed images employing different photogrammetric software systems

The object of the analysis is the North wall of the Vilnius University in the Vilnius old town. Three images were taken by using the *Canon EOS 1D Mark III* digital camera (Fig. 5).

These images were processed by using two different photogrammetric software solutions: *PhotoMod* (Russian) and *Inpho* (Germany) as well as system *Bluh* (Germany). For the calculation of the triangulation with *PhotoMod* software we used the images with the old camera calibration parameters (year 2008) and new calibration parameters (year 2011) (Table 3). The images have been corrected according to the new camera distortions and processed by software *Inpho* and system *Bluh* (Table 3). The results of the mean value (E_{mean}), *RMS* of the images measured *GCP* and tie points and the standard deviation of weight (σ_0) were observed after the calculation of the bundle block adjustment. The summarized results of the calculated discrepancies (residuals) are provided in Figs. 6-7.

Fig. 5. Three overlapping images (P15-P12-P18)

As Figs. 6-7 indicate the results achieved with *PhotoMod*, *Inpho* and *Bluh* corresponded to the accuracy requirements for the measurements in image space: the values $E_{xy(mean)}$ do not exceed 4.0 µm, $E_{z(mean)}$ – 11 µm (Fig. 6). These results are acceptable and do not exceed the values taken in Table 1. The *RMS* is 3 – 14 µm (Fig. 7). This result exceeds the maximum root mean square error calculated by digital camera *Canon EOS 1D Mark III* (Table 1). But the final result of triangulation – standard deviation (σ_0) was achieved 0.5 µm (0.1 pixel size) and 1.4 µm (0.2 pixel size) by using the digital photogrammetric software *Inpho* and system *Bluh* respectively (Table 4).



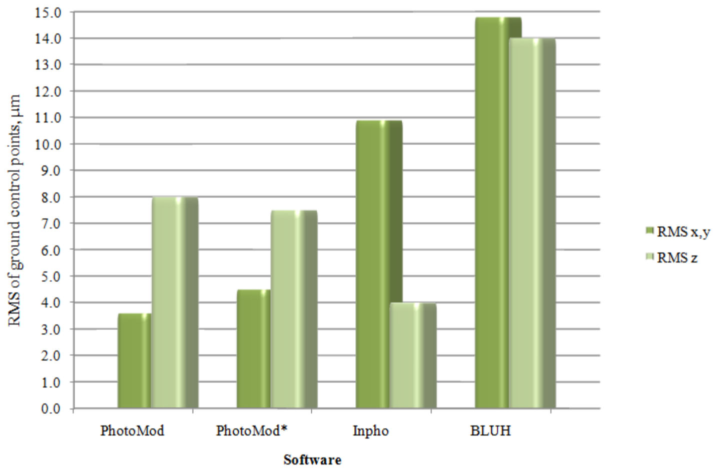
* - images were processed with new camera calibration parameters by *AICON*

Fig. 6. Results of mean value of measurement points in image space (E_{mean})

Table 4. Result analysis of image processing with different software systems

Software	*PhotoMod*	*Inpho*	*Bluh*
σ_0, µm	–	0.5	1.4

The obtained results indicate that the images processed by software *PhotoMod*, *Inpho* and *Bluh* are suitable for the close-range photogrammetry purposes. After good results of calculation of triangulation are received it is possible to create the accurate orthophoto (mosaic) break lines, DTM at the object and use the data for the registration and control of the object structure and deformations.



* - images were processed with new camera calibration parameters by *AICON*

Fig. 7. Results of the RMS value

5. Conclusions

The conducted study leads to the following conclusions:

1. Camera *Canon EOS 1D Mark III* has been calibrated at the Neubrandenburg University of Applied Sciences by using software *AICON* special test-field. The estimated standard deviation (σ_0) value is 5 µm. This result has demonstrated that reliable parameters of camera calibration were obtained.
2. The camera was calibrated at the Bonn University three years ago. The old and new calibration parameters were slightly changed. The parameters which were received during camera calibration processes three years ago remained unchanged during all the time the camera was in use. Consequently, the camera has to be recalibrated when it is mechanically broken or when the camera work parameters (focusing of objective, sensibility) are changed.
3. The quality of the images depends on the errors of camera objective optics, the stability and dynamic movements of the camera during the exposure time. The analysis demonstrated that camera *Canon EOS 1D Mark III* calibration parameters have not undergone appreciable changes, but the stability and dynamic movement could be better. The stability and dynamic movement of the camera have reduced the *x*-parallax error during the image processing time. This error does not exceed the potential point measurement accuracy of < 1 µm in the images.
4. Image processing results achieved with *PhotoMod*, *Inpho* and *Bluh* softwares corresponded to the accuracy requirements for the measurements in the image space: the values $E_{xy(mean)}$ do not exceed 4.5 µm, $E_{z(mean)}$ – 17 µm, the *RMS* are more 3 – 14 µm. The final result of the triangulation – standard deviation of the unit weight (σ_0) is equal to 0.5 µm (0.1 pixel size) and 1.4 µm (0.2 pixel size) by using digital photogrammetric software *Inpho* and system *Bluh* respectively. The results are excellent. Reliable results of calculation of triangulation enable generation of accurate orthophoto (mosaic), break lines, DTM at object.

5. By using new camera calibration parameters the triangulation procedure was performed using digital photogrammetric system *PhotoMod* , the values of the accuracy requirements of the measurement $E_{z(mean)}$ and *RMS z* are better than for the case of old calibration parameters. In the object stereo views there were beheld height discrepancy. Therefore, these discrepancies will have to be analyzed, tested and compared with the geodetic measurements.
6. The results of triangulation obtained were derived by software supplied accuracy requirements. According to this, it is possible to state that the digital photogrammetric systems *PhotoMod* and *Inpho* which are developed for the processing of scanned aerial film frames, the images from various satellite sensors could be used for the close-range photogrammetry as well.
7. Digital image processing was important for the experience and skills of an operator during the stereo or mono measurement procedures in the digital images. The obtained stereo measurements in the images are more precise than the mono measurements, particularly in *Z* – height coordinate.

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References

[1] **Jacobsen K.** PC-Based Digital Photogrammetry. Institute for Photogrammetry and Engineering Survey, University of Hannover, Germany. 25–29 March 2001.
[2] **Kiseleva A. S.** Accuracy control at various stages of photogrammetric processing in PhotoMod system. Racurs. Moscow, Russia. 2002.
[3] **Sužiedelytė-Visockienė J., Kumetaitienė A., Bagdžiūnaitė R.** Accuracy analysis of different surface reconstruction modelling methods of heritage objects, digitalized according to photogrammetric data. Geodezija ir kartografija. Vilnius: Technika, 2011, t. 37 (2), p. 56–62.
[4] **Luhmann T., Robson S., Kyle St., Harley I.** Close range photogrammetry. Principles, Methods and Applications. Scotland, United Kingdom. 2006, p. 60.
[5] **Kersten Th.** Results of digital aerial triangulation using different software packages. OEEPE Workshop on Automation in Digital Photogrammetric Production, Paris, June 21–24, 1999.
[6] **Sužiedelytė-Visockienė J., Bručas D.** Influence of digital camera errors on the photogrammetric image processing. Geodesy and Cartography, 2009, Vol. XXXV, No. 1.
[7] **Abraham S.** Tcc - a software for test field based self-calibration of multi – camera – systems. Institut für Photogrammetrie, Universität Bonn. 2004, p. 39.
[8] **Wojtas A. M.** Off-the-shelf close – range photogrammetric software for cultural heritage documentation at Stonehenge. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXVIII, Part 5. Commission V Symposium, Newcastle upon Tyne, UK. 2010.
[9] **Sanz-Ablanedo E., Rodríguez-Pérez J. R., Armesto J., Taboada M.** Geometric Stability and Lens Decentering in Compact Digital Cameras. MDPI Journal. Sensors 2010, p. 1553–1572.
[10] **AICON** 3D Systems GmbH. Aicon 3D Studio User Manual. Braunschweig, Germany. 2009, p. 5–42.