Journal of International Scientific Publications:
Materials, Methods & Technologies, Volume 7, Part 1
ISSN 1313-2539, Published at: http://www.scientific-publications.net

ACCURACY ANALYSIS OF MEASURING CLOSE-RANGE IMAGE POINTS

Jūratė Sužiedelytė-Visockienė[1], Renata Bagdžiūnaitė[2]

[1] Department of Avionics, Antanas Gustaitis' Aviation Institute, Vilnius Gediminas Technical University, Rodūnios kelias 30, LT- 02187 Vilnius, Lithuania

[2] Department of Geodesy and Cadastre, Faculty of Environmental Engineering, Vilnius Gediminas Technical University, Sauletekio av. 11, LT-10223 Vilnius, Lithuania

Abstract

The performed investigations are aimed at estimating the accuracy of image processing using different image point measurements. For this purpose, digital close-range images were processed applying photogrammetric software PhotoMod. The measurements have been made employing two methods: stereo and manual mode. Two or more overlapping images are matched when control and tie points are estimated. The images of two objects have been taken for experimental investigation. Control points and tie points were measured switching either to stereo or manual mode applying the required software. The control points of the first object are distributed on the surface of a smooth facade and on the surface of different (a few) levels. The process of image matching includes the calculation of the correlation coefficient, vertical parallax residuals and the root mean square of the object. Following image transformation (adjustment processes) to the created 3D model, the accuracy of the measured points is determined. All these values show the precision of close-range photogrammetric processes. Such accuracy satisfies requirements for creating a proper digital terrain model and orthophoto generation.

Key words: *close-range photogrammetry, correlation coefficient, manual mode, stereo mode*.

1. INTRODUCTION

The photogrammetric method of object measurement processes consists of taking images of an object employing a professional calibrated photo-camera and processing these images applying appropriate software. To obtain highly accurate and reliable results, it is necessary to control the capture of photo images and processing accuracy. The processes of photogrammetric images cover relative and absolute orientation, bundle adjustment, stereo-digitalisation, digital terrain model generation and orthophoto creation. A geometric model of the object is made of relative orientation that embraces the interior orientation of the image and matching the image. The point measurements of the images can be divided into two methods: stereo mode and manual mode. When the geometric model of the object is produced using stereo mode, an operator can measure the points (control (*CP*) and *Tie* points) with special glasses. The operator can observe a three-dimensional object through the image view on the computer screen and carry out measurements in both photo images at the same time. During manual measurements, the points are estimated separately in each of the images and then processed adopting a correlation approach or applying to least-square adjustment techniques. The value of correlation coefficients shows how accuracy at that particular point is measured. The quality of the obtained results is estimated by vertical parallax residuals in the measured points and root mean square (*RMS*) geometric models.

The goal of the carried out experiments is to respond to the below introduced questions:

1. What available and acceptable maximum value of the correlation coefficient will be used for measuring the points employing manual methods in overlapping images?
2. What errors of vertical parallax residuals and *RMS* will be used for measuring manual or stereo modes in overlapping images?

2. CALCULATION OF THE CORRELATION COEFFICIENT

The correlation coefficient is used for a close range photogrammetric application of image point measurements. Applications include a comparison of two overlapping images for the purposes of image registration, *CP* or *Tie* point recognition and measurement. The correlation coefficient (q) is calculated according to the formula (Potůčková, 2004; Mileškaitė, 2011):

$$q = \frac{q_{LR}}{q_L \times q_R}, \tag{1}$$

where q_{LR} – covariance of left and right image patches; q_L – standard deviation of image patch L (left image); q_R – standard deviation of image patch R (right image).

The correlation coefficient (q) has value $-1 \le q \ge 1$ if two overlapping images are absolutely identical, $q = 0$ if they are completely uncorrelated (stereo point measurement) and $q = -1$ if they are completely anti-correlated when the left image is a negative right image.

For digital colour image processing, an equation for the correlation coefficient can be modified using a mean value of three channels as a single similarity measure (Potůčková, 2004; Mileškaitė, 2011):

$$q = \frac{q^{red} + q^{green} + q^{blue}}{3}. \tag{2}$$

Correlation coefficients are calculated considering two overlapping images during the relative orientation of photogrammetric processes in the following way (Hanke, 2002):

1. Measuring Tie points of stereo pairs (models) in overlapping areas and triplet zone (in case we have more than two images) images;

2. Input value of coordinates and measuring *CP* in the overlapping image;

3. Accuracy control using the correlation coefficient that is calculated applying the manual point measurement method in overlapping images. When the points are measured by stereo mode, the correlation coefficient is not calculated ($q = 0$);

4. Accuracy control using vertical parallax residual. After measuring the points on the images, the relative orientation parameters of the images are calculated. They are the maximum error of vertical parallax residuals ($E_{\max}$) and the root mean squared error (*RMS*) (Kiseleva, 2002):

$$E_{\max} = 2 \times E_{mean},$$
$$RMS = \sqrt{2} \times E_{mean}, \quad (3)$$

where E_{mean} – is a mean error of measurement points on the overlapping images. This error should not be greater than half of matrix pixel size for digital camera.

After measuring Tie and *CP* in stereo pairs (models), they should be transferred to the geodetic coordinate system. Relative orientation accuracy can be checked comparing the discrepancies of point measurements in adjacent models (triplets). Triplet errors E_X, E_Y, E_Z, in their coordinates X, Y and Z were calculated for two adjacent models. The mean errors of measurement points in the XY plane and Z coordinates are calculated by the following formulas (Kiseleva, 2002):

$$E_{xy(mean)} = \sqrt{2} \times 0.5 \times pxl,$$
$$E_{z(mean)} = \frac{c}{b_x} E_{xy(mean)}, \quad (4)$$

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

3. EXPERIMENTAL WORKS

To evaluate the possibilities of point matching methods creating the 3D model, the fragment of two heritage objects was chosen. The first one is a church built in 1881 in the settlement of Raudenai, Šiauliai municipality, Lithuania. The second object is a farm building in Arnioniai manor, Moletai municipality, Lithuania. Both objects were reconstructed last year. During reconstruction, it was necessary to have photogrammetric fixation of the object facade.

Thus, colour digital images of two objects were taken by the professional digital photo-camera *Canon EOS 1D Mark III* (Figs 1 and 2) that was calibrated (optical distortions were determined and evaluated) using *Tcc* software at the Institute of Photogrammetry in the University of Bohn (Germany) in 2008 and 2012 (Sužiedelytė-Visockienė; Bručas, 2009 a, b; Sužiedelytė-Visockienė, 2012). The focal length of the camera is 50.76 mm and pixel size in a camera matrix *pxl* = 6.4 μm.

The facade of the first object (house) has a smooth surface (Fig. 1). The facade of the second object is advanced and has two different point measurement levels of the surface (Fig. 2). *CP* and *Tie* points are marked on the facade. All these points are used for the relative orientation of photogrammetric processes. *CP* have been measured considering the images of the manual (mono) and stereo modes of the first object. The correlation coefficients (q) and vertical parallax residual (E) of the measured points have been calculated following the measurement. Accuracy results are shown in Table 1.

ISSN 1313-2539, Published at: http://www.scientific-publications.net

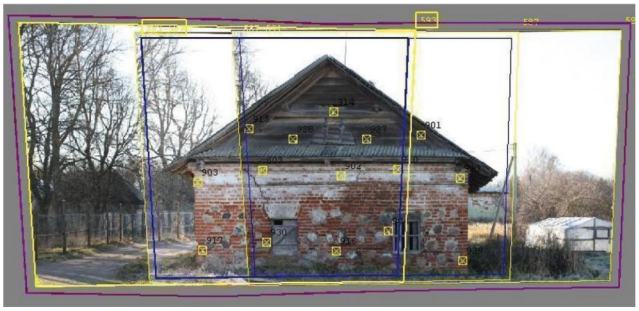

Fig. 1. Three overlapping images (593/587/591)

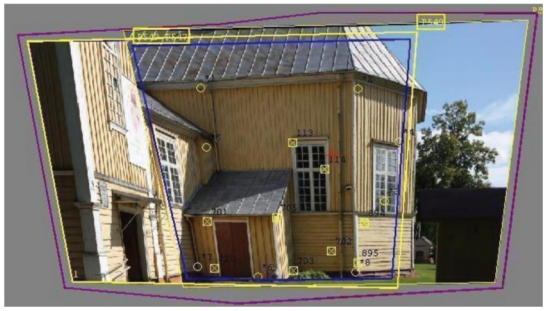

Fig. 2. Two overlapping images (547/549)

Table 1. Accuracy analysis of point measurements using manual modes of the first object

No of CP points	***q***	***E, pxl***	***q***	***E, pxl***
Model of 593/587			*Model of 587/591*	
803	0.996	-0.011	0.997	0.002
901	-	-	0.998	0.040
902	0.994	0.014	0.997	0.006
903	0.992	-0.012	-	-
904	0.996	-0.133	0.996	0.148
910	0.994	0.018	0.997	-0.014
913	-	-	0.998	-0.067
914	0.995	0.019	0.997	-0.024
915	0.995	-0.001	-	-
916	0.997	0.070	0.997	0.094
917	0,995	-0,130	-	-
927	0,995	-0,026	0,998	0.006
928	0,994	0,006	0,996	0.009
929	-	-	0,997	-0.078

930	0,995	0,184	0,997	-0.119
$E_{mean} = 0.079\ pxl$ RMS=0.111 pxl			$E_{mean} = 0.070\ pxl$ RMS=0.099 pxl	
The result of image adjustment $E_{xy(mean)} = 0.003$ m, $E_{z(mean)} = 0.001$ m				

The correlation coefficients (q) of the measured points have not been calculated in stereo mode. The results of vertical parallax residuals are shown in Table 2.

Table 2. Accuracy analysis of point measurements using stereo modes of the first object

No of CP	***E, pxl***	***E, pxl***
points	*Model of 593/587*	*Model of 587/591*
803	–0.084	–0.513
901	–	0.229
902	0.140	0.017
903	–	
904	0.161	–0.196
910	–0.056	0.084
913	–	0.334
914	0.037	–0.744
915	0.133	0.827
916	–0.068	0.154
917	0.012	–
927	0.000	–0.106
928	–0.193	–0.008
929	–	
930	–0.281	0.060
	$E_{mean} = 0.148\ pxl$ RMS =0.209 pxl	$E_{mean} = 0.369\ pxl$ RMS =0.522 pxl
The result of image adjustment $E_{xy(mean)} = 0.003$ m, $E_{z(mean)} = 0.001$ m		

The results of the first object show that the relative orientation and image adjustment of measuring manual and stereo points (Tables 1 and 2) are of similar and good quality. Consequently, if an object has a smooth surface, it is possible to measure the points manually or by stereo mode. The correlation coefficient (q) is 0.992–1.00.

As for the second object, two overlapping images (Model 549/547) have also been measured using CP manual and stereo modes. Accuracy results are shown in Tables 3 and 4.

Table 3. Accuracy analysis of point measurements using manual modes of the second object

No of CP	***q***	***E*, pxl**
points	*Model of 549/547*	
701	0.991	–1.962
720	0.987	–0.407
703	0.994	–1.238
702	0.990	0.126
114	0.989	2.254
113	0.956	1.904
895	0.963	–0.066
894	0.974	1.061
E_{mean} = 1.387 pxl *RMS* =4.997 pxl		
The result of image adjustment $E_{xy(mean)}$ = 0.035 m, $E_{z(mean)}$ = 0.082 m		

Table 4. Accuracy analysis of point measurements using stereo modes of the second object

No of CP	***E, pxl***
Points	*Model of 549/547*
701	–0.304
720	0.435
703	0.308
702	–0.063
114	–0.408
113	0.115
895	–0.160
894	0.127
E_{mean} = 0.148 *pxl*; *RMS* =0.284 *pxl*	
The result of image adjustment $E_{xy(mean)}$ = 0.003 m, $E_{z(mean)}$ = 0.005 m	

The results of the second object indicate that the relative orientation and image adjustment of manual and stereo point measurements (Tables 3 and 4) are different. The results of the points measured in stereo mode are good enough; the mean errors of measurement points in the XY plane and Z coordinates are small. The results of point measurements and image adjustment applying manual mode disclose big blunders ranging from 0.03 to 0.08 m. Consequently, if the points are measured on more than one surface, it must be done in stereo mode. The correlation coefficients of the image adjustment of manual mode are 0.960–0.991.

A comparison of the point vertical parallax E_{mean} of measurement points on overlapping images and RMS image processing in manual and stereo modes are shown in Figs 3 and 4.

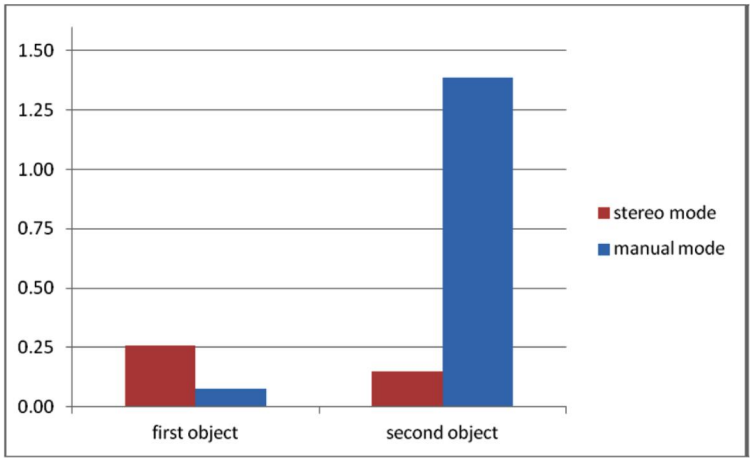

Fig. 3. Values of vertical parallax E_{mean} in *pxl*

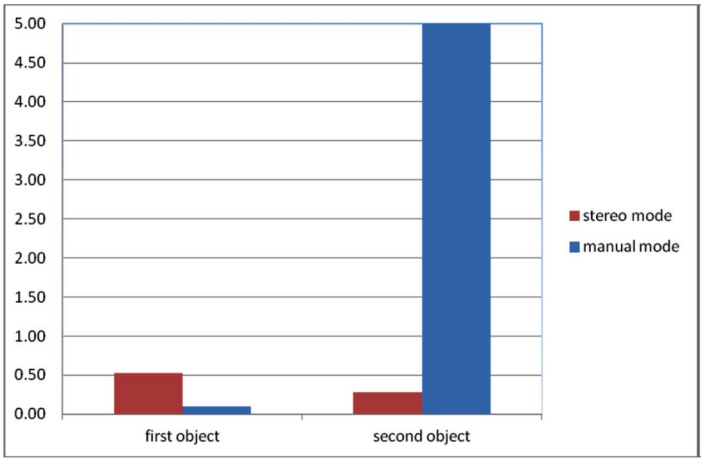

Fig. 4. Value of *RMS* in *pxl*

A comparison of the results of image adjustment $(E_{xy(mean)}, E_{z(mean)})$ in the images of manual and stereo modes are shown in figures 5 and 6.

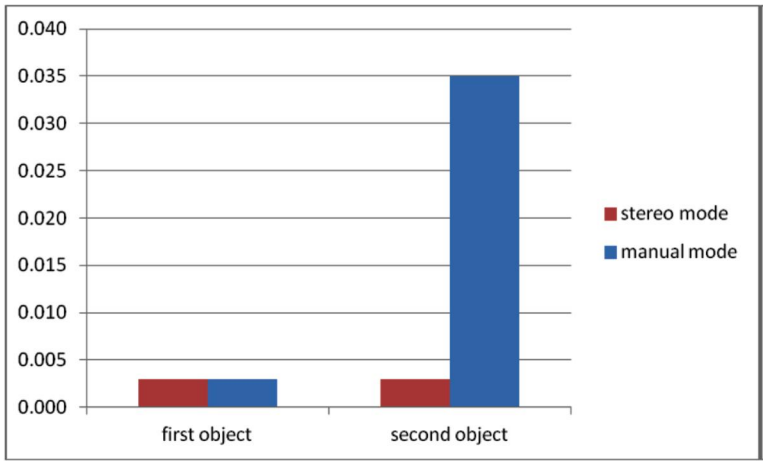

Fig. 5. Value of mean errors $E_{xy(mean)}$, in m

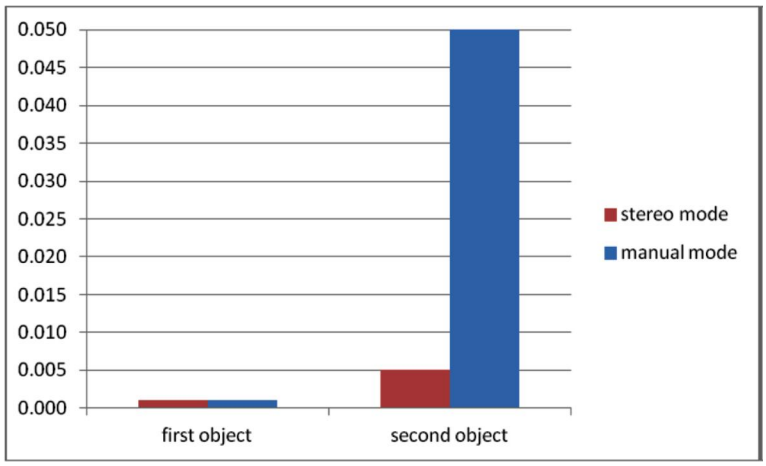

Fig. 6. Value of mean errors $E_{z(mean)}$ in m

Figures 3–6 clearly indicate that the point measurements of the second object using manual (mono) mode has unacceptable errors, whereas the point measurements of the first object has been done using manual or stereo mode.

4. CONCLUSIONS

The images of two heritage objects have been taken for experimental investigation. Control points and tie points have been measured using stereo and manual mode. The control points of the first object are distributed on the surface of the smooth facade and on the surface of different (a few) levels.

The process of image matching of the smooth surface object points to the value of the determined correlation coefficient, which makes 0.992–1.00. The mean error of the vertical parallaxes of the measured points makes E_{mean} = 0.07–0.15 *pxl* and root mean squared *RMS* = 0.01–0.21 *pxl*. After image transformation (adjustment processes) to the 3D model, the accuracy of the measured points has reached 0.001–0.003 m and satisfies the requirement for creating an accurate digital terrain model and orthophoto generation.

Within the process of matching an image with an object having a different surface, the value of the correlation coefficient, which is 0.960–0.991, has been determined. The mean error of the vertical parallax of the measured points is E_{mean} = 1.4 *pxl* and *RMS* = 5 *pxl* when points are measured manually. The result of image adjustment makes 0.04–0.08 m. When the points are measured by stereo mode, vertical parallax E_{mean} = 0.15 *pxl* and *RMS* = 0.28 *pxl* and image adjustment result is 0.03–0.05 m. The results of stereo mode are more precise than those of manual mode.

Considering close-range photogrammetry during relative orientation, it is recommended that the value of the correlation coefficient should be not smaller 0.990. The precise results of point measurements are obtained using stereo mode.

REFERENCES

Hanke, K.; Grussenmeyer Corfu P. 2002. *Architectural Photogrammetry: Basic Theory, Procedures, Tools*. [online], 27 p. Viewed 20 January 2013,

<http://www.isprs.org/commission5/tutorial02/gruss/tut_gruss.pdf>.

Kiseleva, A. S. 2002. '*Accuracy Control at Various Stages of Photogrammetric Processing in PhotoMod System'*. Moscow: Racurs. Russia.

Mileškaitė, J. 2011. 'The application of the covariance method analysing the digital images of land surface'. *Geodezija ir kartografija* [Geodesy and Cartography] 37(3): 105–110, viewed 23 April 2013, <http://dx.doi.org/10.3846/13921541.2011.626260>.

Potůčková, M. 2004, 'Image Matching and Its Applications in Photogrammetry', Ph.D thesis Technical University of Prague [online], 149 p. Viewed 25 January 2013, <http://www.plan.aau.dk/digitalAssets/5/5516_314.pdf>.

Sužiedelytė-Visockienė, J.; Bručas, D. 2009 (a). 'Digital photogrammetry for building measurements and reverse-engineering', *Geodezija ir kartografija* [Geodesy and Cartography] 35(2): 61–65, viewed 23 April 2013, <http://dx.doi.org/10.3846/1392-1541.2009.35.61-65>.

Sužiedelytė-Visockienė, J.; Bručas, D. 2009 (b). 'Influence of digital camera errors on the photogrammetric image processing', *Geodezija ir kartografija* [Geodesy and Cartography] 35(1): 29–33, viewed 23 April 2013, <http://dx.doi.org/10.3846/1392-1541.2009.35.29-33>.

Sužiedelytė-Visockienė, J. 2012. 'Photogrammetry requirements for digital camera calibration applying Tcc and MatLab software', *Geodezija ir kartografija* [Geodesy and Cartography] 38(3): 106–110, viewed 23 April 2013, <http://dx.doi.org/10.3846/20296991.2012.728895>