PRECISION AND RELIABILITY OF GPS-COORDINATES OF PROJECTION CENTRES IN REAL AERIAL TRIANGULATIONS

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ABSTRACT:

The aim of this study was to determine the precision of GPS-coordinates of projection centres obtained in photogrammetric production in Poland. The second aim of the work was to estimate the reliability of this group of measurements in aerial triangulations performed for three scales of aerial photographs. The study was based on repeated processing of data from production blocks, in comply with conditions of a correct adjustment. Adjustments were preceded by the pre-adjustment detection of gross errors and improper division of data into GPS profiles. Production results originated from various measurement systems and adjustment softwares; and they were characterized by numerous imperfections related to functional and statistical model and being generally the result of the applied technologies. A set of 25 blocks was selected for testing, including three scales of aerial photographs: 1:13 000, 1:19 000 and 1:26 000, most frequently used in Poland. Number of photographs in one block varied from 136 to 3402, and the total number of photographs in all blocks was about 30 000. The corrected a priori standard deviation of GPS-coordinates obtained from 25 adjustments reached 10.7 cm on average. The analysis of global internal reliability of GPS-coordinate for particular scales revealed that in blocks of photographs at scale 1:13 000 the average redundancy numbers reached 0.50 for X, 0.48 for Y and 0.75 for Z coordinate. So, it can be concluded, the reliability of GPS-coordinates of projection centres in these aerial triangulations was good. For scales 1:19 000 and 1:26 000, in 9 blocks out of 15 the global redundancy numbers of horizontal GPS-coordinates were lower than 0.25.

1. INTRODUCTION

The correctness of the network adjustment depends on selection of the proper functional model, on applying proper weights of measurements and on elimination of mistakes and gross errors. The fulfillment of these conditions in aerial triangulation may be troublesome as there are three groups of measurements different in character and origin, namely: ground control point coordinates, photo coordinates and projection centre coordinates. In these groups of measurement the precision is often only roughly defined. This makes difficult the weighting of measurements and the elimination of gross errors. The problem is particularly related to measurements of GPS-coordinates of the projection centres, as the observers report the precision with too low accuracy or do not give it at all.

The first aim of the research was to determine the precision of measurement of the projection centres in aerial triangulations made in Poland during last few years. This information will enable to assign realistic values to precision of projection centre measurements in simulations used in designing the aerial triangulation scheme and also in adjustments to assign more realistic values for a priori standard deviation where it is not specified by the observer. For the photogrammetric practice it is a significant fact, that not all production software used for the aerial triangulation adjustment in Poland enable to calculate the aposteriori standard deviation for each group of observations, which makes impossible to verify the observation weighting.

The second aim of the research was to determine the reliability of this group of measurements in aerial triangulations made for three scales of aerial photographs used in Poland most often. The reliability of measurements is after precision the second factor affecting the accuracy, and if the reliability level is too low it is difficult to detect and locate gross errors. The comparison of the reliability criteria and the average reliability level gained in production blocks of the same scale of photographs could be an argument for changes in the technology of designing the aerial triangulation scheme.

2. METHOD

The evaluation of the precision of GPS-coordinates was based on the repeated processing of the production blocks in comply with the conditions of a correct adjustment. Production data originated from various measurement systems and adjustment softwares. They were characterized by numerous imperfections in functional and statistical models resulting generally from the applied technologies. Following cases could be counted as faults in aerial triangulation procedure applied for photogrammetric production:

- some blocks were adjusted without additional parameters which is against standards,
- mainly the Ebner 12-parameter model was applied, which is not a fault but in more demanding projects model of additional parameters should be used with higher number of parameters,
- short GPS profiles were adjusted including drift parameter which unnecessary weakened the network,
- used in production the procedure of pre-adjustment verification of GPS measurements to detect

mistakes and gross errors is not appropriate to detect improper division of GPS data into profiles,
- in some projects the applied software had no variance-component estimation for each group of measurements which made impossible any correction of a priori standard deviation used in adjustments,
- in large number of projects the detection of gross errors was based solely on residuals of measurements which was insufficient in situation of low reliability level of the measurements.

The conditions mentioned above prompt the author to repeat the processing of production measurements in comply with the following rules:
- adjustments were made with the use of BINGO software with the model of 24 additional parameters based on the works of H. Bauer, J. Mueller, K. Jacobsen and E. Kruck being the author of the software,
- pre-adjustment tests to detect gross errors and improper division of GPS measurements into profiles were made with the use of the method developed by the author of this paper (Ziobro, 2006). The method is based on the analysis of two independent processes: the first is the result of the aerial triangulation adjusted without determining the projection centres, and the second is the result of projection centre measurements made during the photogrammetric flight. Then the distances between neighbouring points in the GPS profile obtained from two independent determinations are compared. The differences greater then their triple mean error are considered gross errors or changes of shift in a GPS profile.
- short GPS profiles were adjusted including shift parameter only,
- the analysis of gross error presence in the net was made with the use of the data snooping method by W. Baarda,
- for each group of measurements the value of an a priori standard deviation was corrected during adjustments. The a priori standard deviations were verified after each iteration step until they reached 5% consistency level in the aposteriori/apriori test for each group of measurements,
- basing on the results of the block adjustment the global redundancy number of GPS-coordinates was determined as an average of local redundancy numbers.

Photo scale	Number of blocks	Number of photos per one ground control point	A priori std dev of coordinate of ground control points [cm]		Number of tie points on one photo	A priori std dev of photo coordinates [μm]
			horizontal	vertical		
1	*2*	*3*	*4*	*5*	*6*	*7*
1:13 000	10	12	18	31	37	4.4
1:19 000	4	9	27	32	23	6.5
1:26 000	11	11	46	27	38	5.1

Table 1. Selected characteristics of blocks as the average for each photo scale

3. DESCRIPTION OF TEST BLOCKS

To perform a test, a set of 25 blocks was selected, including three scales of aerial photographs most frequently used in Poland during last few years: 1:13 000, 1:19 000 and 1:26 000. An important characteristic of selected blocks was the presence of projection centre measurements (supplied for 90% of photographs in the block, on average). The number of photographs in one block varied from 136 to 3402, and the total number of photographs in all blocks was about 30 000. Photo-identifiable terrain features served as ground control points in these blocks. The blocks made from photographs at scale 1:13 000 and 1:26 000 are large and rectangular in shape. The blocks of photographs at scale 1:19 000 are irregular in shape with zigzag outer boundary. The other characteristics of blocks are given in Table 1 as the average values for each scale.

4. RESULTS

The results of adjustments of projection centre measurements are grouped by scale of aerial photographs mentioned earlier in three tables numbered 2, 3 and 4. In column 4 of each table there are the corrected a priori standard deviations of GPS-coordinates (equal for all three coordinates), which could be regarded as the precision of measurement. These values form a 25-element sample for which some basic characteristics can be calculated: sample mean - 10.7 cm; standard deviation – 4.1 cm and range – 15.1 cm (Ney, 1976).

No.	Block name	Number of observations of projection centres	A priori std dev of GPS--coordinates [cm]	Average local redundancy numbers of GPS-coordinates			RMS residual of GPS-coordinates [cm]		
				r_X	r_Y	r_Z	RMS_X	RMS_Y	RMS_Z
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1	1-68	1924	13.3	0.53	0.54	0.85	11.5	11.3	9.8
2	3-68	1623	15.6	0.76	0.75	0.85	15.5	13.7	12.5
3	4-68	1549	8.1	0.42	0.41	0.76	5.1	7.1	5.1
4	5A-68	846	5.2	0.51	0.49	0.80	3.6	3.7	3.6
5	5B-68	1011	9.2	0.53	0.50	0.83	7.7	7.9	5.8
6	7-68	2006	5.8	0.40	0.38	0.76	3.9	3.8	4.0
7	8-68	1923	8.1	0.42	0.41	0.77	5.8	5.9	5.0
8	9-68	2249	6.4	0.42	0.39	0.72	4.6	4.4	4.0
9	10-30	1392	20.2	0.49	0.44	0.70	15.4	17.6	11.8
10	13-30	1033	10.4	0.47	0.45	0.77	7.1	7.9	7.9
Average		-	10.2	0.50	0.48	0.78	8.0	8.3	7.0

Table 2. Results of the block adjustments for photo scale 1:13 000

No.	Block name	Number of observations of projection centres	A priori std dev of GPS--coordinates [cm]	Average local redundancy numbers of GPS-coordinates			RMS residual of GPS-coordinates [cm]		
				r_X	r_Y	r_Z	RMS_X	RMS_Y	RMS_Z
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1	C-16	268	20.3	0.27	0.27	0.64	10.6	11.9	14.4
2	G-1	303	11.5	0.44	0.43	0.75	8.7	8.0	8.8
3	G-2	136	7.8	0.26	0.29	0.66	4.2	4.5	6.3
4	J-20	359	7.9	0.13	0.12	0.50	3.3	3.3	5.0
Average		-	11.9	0.28	0.28	0.64	6.7	6.9	8.6

Table 3. Results of the block adjustments for photo scale 1:19 000

No.	Block name	Number of observations of projection centres	A priori std dev of GPS--coordinates [cm]	Average local redundancy numbers of GPS-coordinates			RMS residual of GPS-coordinates [cm]		
				r_X	r_Y	r_Z	RMS_X	RMS_Y	RMS_Z
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1	2-1	331	8.1	0.16	0.14	0.56	3.4	3.4	5.3
2	2-2	314	6.9	0.15	0.13	0.54	2.8	2.8	4.7
3	2-a	769	10.4	0.23	0.21	0.64	5.3	5.4	6.9
4	2-b	1510	10.4	0.22	0.20	0.63	5.4	5.5	7.1
5	2-c	1211	8.7	0.18	0.16	0.57	4.1	4.2	5.9
6	3-3	2996	13.3	0.51	0.50	0.78	10.5	10.1	9.7
7	4-7	270	7.5	0.17	0.18	0.60	3.0	3.3	5.9
8	4-a	1261	16.7	0.37	0.34	0.71	10.8	12.6	10.1
9	4-b	2088	10.4	0.22	0.20	0.61	5.4	5.6	6.7
10	4-c2	313	11.5	0.22	0.20	0.60	6.5	5.7	7.5
11	4-d	932	12.7	0.26	0.25	0.66	7.2	7.9	7.8
Average		-	10.6	0.24	0.23	0.63	5.9	5.9	7.0

Table 4. Results of the block adjustments for photo scale 1:26 000

The mean precision value could be used as an a priori standard deviation of measurements in simulations used in designing the aerial triangulation scheme and also in adjustments where an a priori standard deviation is not specified by the observer.

Using a scale of photographs as a grouping factor for the analysed blocks resulted mainly from the observation that when the first component of the accuracy of projection centre measurement, i.e. precision, is scale independent, the second component - the reliability, depends on the scale (Li, et al., 1989). In columns 5 to 7 of the tables there is the average local redundancy number of the GPS-coordinate being a measure of its global internal reliability. In columns 8 to 10 there are RMS residuals of GPS-coordinates. On the basis of publications on the network quality (Barrot, et al., 1994; Casaca, 1987; Gruen, 1980; Foerstner, 1985; Kruck, 2006; Prószyński et al., 2002), one can roughly assume that the ability to detect gross errors is good when the redundancy number is close to 0.50 or greater. Values under 0.25 indicate insufficient reliability of measurements and consequently, low level of gross error detection.

The analysis of global internal reliability of GPS-coordinates for particular scales revealed that in blocks of photographs at scale 1:13 000 the average local redundancy numbers reached 0.50 for X, 0.48 for Y and 0.75 for Z coordinate. Therefore, it can be concluded that the reliability of GPS-coordinates in these aerial triangulations was good. In these blocks the average RMS residuals of all three GPS-coordinates constituted roughly 76 % of the average a priori standard deviation.
Different situation was in blocks of photo scale 1:19 000 and 1:26 000. The results presented in Table 3 and Table 4 showed that in 9 blocks out of 15 the average local redundancy numbers of horizontal GPS-coordinates were lower then 0.25. Good level of reliability was gained only in the block 3-3 (No 6 in Table 4). The reason for higher reliability in this block in relation to other blocks is higher precision of the ground control points and numerous 6-fold tie points. In these blocks the average RMS residual of GPS-coordinates constituted only 56 % of the a priori standard deviation.

5. CONCLUSION

The average precision of measurement of the GPS-coordinates in aerial triangulations made in Poland during last few years is 10.7 cm. This average precision being determined on the basis of quite numerous sample of examined blocks can be applied as the a priori standard deviation in simulations used in designing the aerial triangulation scheme and also in adjustments where the a priori standard deviation is not specified by the observer.
The research also revealed good global internal reliability of measurements in aerial triangulation blocks at photo scale 1:13000. In blocks at photo scale 1:19 000 and 1:26 000 the reliability of horizontal GPS-coordinates was in many cases insufficient and therefore the procedure of designing the aerial triangulation scheme for these scales of photographs should be modified.

6. REFERENCES

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