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Presented Paper

Strip Semianalytical Aerotriangulation by Independent Models in the Railway Surveying of Czechoslovakia.

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A b s t r a c t .

The paper deals with a modification of the semianalytical strip aerotriangulation by independent models /SAT/,with help of which is created the point field for the production of the United Railway Map /scale 1:1000/ in the CSSR. Photogrammetric measurements are provided by autograph Wild A10 and by Data Acquisition System EK22. Calculation part is provided by the computer EC 1033.

Theory of solving is briefly described,it is refered to the mode of bridging and elimination of systematic errors of model strip. The structure of data,limiting of their dimension and their checks in the programme are outlined.

There are requirements on the accuracy of coordinates of determining points mentioned and these requirements are confronted with the results obtained in some territories. Some special tests are described in a paper which were provided during the calculations SAT in an experimental locality.

1. Introduction.

The rapid increase of demands on the map work of the Czechoslovak State Railways /CSR/ and the availability of adequate techniques has called out the need of application of new methods in mapping.
In spite of the fact that the photogrammetry in mapping has been applied for 20 years it is now necessary to make a better use of this method even in the surveying service of the CSR in the creation of United Railway Map /URM/ especially in the preparing of the point field.
Taking into consideration the specialities of the railway body as a line structure, a Semianalytical Strip Aerotriangulation /SAT/ for the creation of detailed geodetic networks for mapping has been chosen. For our purposes the SAT has been modified in [2] and worked out in greater detail in [5] .
The character of railways, where length dimension markedly exceeds the width of an area and the large scale of URM require an adequate adaptation of existing point fields for detailed measurements. That is why the detailed point field is established by surveying methods till the distance of the points is approximately 500 m [1] .
These points will be determined with considerable accuracy, mean square error of the position coordinates m_{XY} = 0,02 m, high error m_h = 0,05 m, and will be applied as geodetic control points for the SAT.
The indisputable advantages of greater safety and rapidity of the work and of reduction of field work have demonstrated the correctness of the development of application of photogrammetric methods to railway surveying in the CSSR.

2. Theoretical Solution of the SAT and Presumptions for its Realization.

If the results of the SAT, coordinates of detailed points, are to comply with the high demands on the accuracy for large-scale mapping, precise equipments must be used for measurements on

stereomodels. The extent and the demanding character of the calculations requires the use a computer.
These conditions were met in 1975 when autograph Wild A10 with peripheral equipments was delivered to our section.
The basic instrument of the whole unit is the autograph A10. Its basic technical data are well known and that is why I would like to mention only the real accuracy of the autograph which was determined before the series of measurements according to [4] - Table I.

Date	c_k /mm/	z /mm/	a' /mm/	b_x /mm/	m'_x /μm/	m'_y /μm/	m_z /‰z/	Remark
27.3.78	150	300	40	120	4	5	0,025	Wild grid

TABLE I

The calculation proper is made on the computer EC1033/internal memory 512 kb,computing speed about 200 000 op.per second/.
The calculation of coordinates of one determined point takes about 4 seconds.
To obtain a theoretical basis for the solution of the problem a close cooperation with the Geodesy Department of the Technical University in Brno has been established.
The existing method was adapted for the universal oriented model strip with regard to the ground coordinate system and some equations were derived again [2] , [5] . The opportunity of adjustment of measurements by the least square method was extensively used.
The solution of the SAT is based on the determination of the position of perspective centers of each aerial image. Every center is fixed as a point of intersection of the redundant number of lines in space. The lines are also fixed by the redundant number of points in the preliminary chosen three planes,independently for each image [3] , [5] . The perspective centers of images form with connection points which lie in the forward overlap of models /max 5 points/ a sufficiently firm spatial body. Linking of separate models into one strip is provided by three dimensional transformation [5] .
For the computing of 7 transformation elements an iterative method for the solving of equations has been used with advantage. The orthogonality of the transformation matrix is controled by a special test.

Coordinates of measured points in every model are independent and that is why was necessary to provide a preliminary numerical absolute orientation before the determining of all new points. As control points are used such of them which are known in advance in the ground system of the coordinates /geodetic system/. To obtain an equivalent coordinate system in space it is necessary before the computing of the absolute orientation to refer the sea levels of these points to a plane and to adjust them to z coordinates. After numerical absolute orientation some corrections and a repeated transformation we get a spatially correct restored model strip on the ground coordinates,of course with the systematic errors from restoring of ray bundles and photogrammetric measurements of single models. Elimination of these errors is provided by a 2nd order polynomial transformation [5].

15 factors of this transformation are determined by adjustment by least square method from six control points at least. These points are to be stagered on the whole space of the model strip, so that it would not be necessary to extrapolate during the calculation of correction of the determined points in the marginal parts of the strip.

Coordinates of the determined points are obtained by corrected transformation matrix which includes the absolute orientation of the model strip and corrections from final spatial transformation. Corrections from the polynomial transformation for all the points are fixed by beforehand calculated coefficients. Finally corrections after the polynomial transformation are computed on control points.

These deviations are the rate of accuracy of determined point coordinates. Finally the z coordinates are adjusted to sea levels.

During the compilation of the technology of the processing of the SAT great attention was given to some checks that must involve all the main sources of errors. These checks may be divided into three groups:

a/ checks of the photogrammetric measurement,

b/ checks of the input data before the calculation by computer,

c/ checks during the numerical calculation.

Ad a/ measurement of the model is carried out in two groups. Discrepancies between groups must not exceed 0,03 mm. If this condition is met,then the arithmetic mean of the two measurements is used in further calculations,

ad b/ the standard tape is subjected partly to logic checks and partly to material checks of the totality and right succession of each sign. Occasional errors request a manual interference of an operator,

ad c/ during the calculation the interresults are compared with various numerical data either constant or converted,that can eliminate points measured with gross errors.

The programme is processed in such a way that in the case of elimination of any erroneous point,for example during the transformation,the cycle of computations is repeated without the elimination point once again and that is why the erroneous point does not affect the other points.

3.The Computing Programme and the Technology of the Photogrammetric Measurement of the SAT.

The whole programme consist of the main programme,named DOUBLE, and 19 subroutines. It is stored in 83 kb of operation memory of the computer.
For the reading of the tape it was necessary to compile a special programme in Assembler language. By this programme the input data for calculations of the SAT were read,sorted and checked. The main programme is compiled in Fortran IV. The extent of the input data is not limited by possibilities of the computer used but by specialities of the working process of the SAT for the purpose of railway mapping.

The scope of the programme DOUBLE.

The number of models in the strip is 2 - 15 /strip length is 740 - 5500 m/.
The number of control points in the strip is 6 - 35.
The number of determined points in the strip,up to 150,with 10

in each model.

The number of control points in one model is 0 - 4.

The filing of the results of calculations and the judging of a structure of mean square errors is enabled by the output form where the following data are given:

a/ the copy of the tape,

b/ lists of each type of points with calculated arithmetic means of the measured coordinates from two groups,

c/ coordinates of control points after three-dimensional transformation and their deviations,

d/ coordinates of control points after polynomial transformation and their deviations,

e/ coordinates and sea levels of determined points.

To obtain results as good as possible it is necessary to limit all the accessible sources of errors of the photogrammetric measurements. In practice it means to center carefully images into the carriers and to eliminate regular shrinkage of the emulsion or the base of slides or negatives.
The rectification of drums for fine fitting of the principal distance at the projectors of the stereoplotter is necessary before the measurement, too.
At first a relative orientation is performed in an arbitrary way. The stereomodel is measured by stereoscopic pointing - connection points, control points, determined points - and also by monoscopic pointing - auxiliary points for the calculation of perspective centers.
Basic data of the locality such as the mean scale of the aerial images and the number of models in a strip are reserved for the automatic calculation of the check number limits. All these data are recorded on a standard five-track tape by DAS EK 22.

4. Some Tests, Survey of Results Obtained and a General Evaluation of the SAT for Purposes of Railway Mapping.

Some experiments were made during the calculations of the SAT, the descriptions and results of which are enclosed.

A. Measurements of photogrammetric data in one group only.

The measurements in one group means a considerable time reduction but the appropriate mistakes in are not affected. The increase in accuracy of point coordinates during the measurement in two groups as against the measurement in one group was studied. The result of the test is expressed by the percentage ratio of the increase of accuracy - Table II.

During all the tests the mean square error according to an equation $m_i = \sqrt{[oo]/n_b}$ was calculated, where n_b is the number of determined points because the geodetic measurement of the points was considered errorless.

			measurements in one group				measurements in two groups				Ratio of deviations /%/	
			Deviations				Deviations					
			control points		determined p.		control points		determined p.		control p	det.p.
c_k /mm/	M_s	number of points	m_X /m/	0,042	m_X	0,063	m_X	0,038	m_X	0,067	93	94
			m_Y /m/	0,048	m_Y	0,069	m_Y	0,042	m_Y	0,062	88	90
152	4700	8/42	m_h /m/	0,017	m_h	0,204	m_h	0,022	m_h	0,194	129	95

TABLE II

Conclusion to Table II.

Though the increase in accuracy during the measurements in two groups is not convincing, it is suitable to proceed in this way because it enables a valuable prevention of gross errors, especially during the identification of the naturally targeted points. A further analysis revealed an increase in the systematic error of coordinates during the measurement in one group.

B. A different number of control points in the same locality.

Deviations on control points after polynomial transformation are the only criterion of the accuracy of the determined points. Table III shows how exactly these deviations reveal the error of the coordinates of the determined points for the various number of ground control points in the strip. The strip of the 7 models was calculated by 8 and by 20 control points. The coordinates and heights of the 50 points were known from independent geodetic field measuring. That is why the errors of the control and determined points in the dependence on the number of the control points could be compared. The result is expressed by the ratio in percents.

c_k /mm/	M_s	number of points	control points		determined p.		Ratio /%/
152	4700	8/42	m_X /m/	0,038	m_X	0,067	56
			m_Y /m/	0,042	m_Y	0,062	68
			m_h /m/	0,042	m_h	0,195	22
		20/30	m_X /m/	0,044	m_X	0,070	59
			m_Y /m/	0,060	m_Y	0,063	82
			m_h /m/	0,113	m_h	0,157	47

TABLE III

Conclusions to Table III.

Values of sets of the errors seem to be brought nearer in the group with 20 control points. The greater number of control points,especially when stagered,approximates more truthfully the field of coordinate deformations of the strip after spatial transformation.

That is why it is necessary to count upon the fact that in the running of the long strips with a small number of control points the precision of the new points will be considerably smaller than the deviations show on the control points.

C.A test of the stability of the result of calculations on incorrectly ordered coordinates of the control points.

Coordinates of control points must be known with considerable precision. In the case of the occurrence of an error in geodetic measurement which does not exclude the control point during the processing of the SAT even the coordinates of the determined points will be changed. Table IV shows discrepancies of the coordinates of the determined points if the error is known.

c_k /mm/	M_s	number of models	number of points	DEVIATIONS A			DEVIATIONS B			Differencies /m/		
				m_X /m/	m_Y /m/	m_h /m/	m_X /m/	m_Y /m/	m_h /m/	dX/m/	dY/m/	dh/m/
152	4650	4	8/12	0,05	0,06	0,22	0,06	0,07	0,29	-0,05	-0,02	-0,10
									Accuracy of control points /m/			
										0,13	0,13	0,13

TABLE IV

Comments on Table IV.

Deviations A : error of the control points the coordinates of which were ordered errorless.

Deviations B : error of the control points the coordinates of which are fraught by error which did not exclude the point out of adjustment.

Conclusion to Table IV.

It is evident that even smaller errors in the geodetic determination of the control points affect the coordinates of the determined points. That is why it is necessary to bear in mind maintaining the requested accuracy of the control points.

Regulations for the URM request the mean square coordinate error in position for points determined in value m_{XY} = 0,06 m, and height error m_h = 0,10 m. Let us see how the results of the adjustment of the SAT in some localities comply with our conditions - Table V.

c_k /mm/	M_s	number of models	number of points	m_X /m/	m_Y /m/	m_h /m/	m'_{xy} /μm/	m_z /‰ z/
210	4450	2	6/8	0,07	0,01	0,02	11	0,02
152	3550	3	7/37	0,03	0,03	0,09	8	0,10
152	4700	7	8/41	0,04	0,04	0,02	9	0,03
152	4700	7	20/30	0,04	0,06	0,11	11	0,16
305	2570	9	7/81	0,02	0,02	0,04	8	0,08
152	4650	4	8/12	0,05	0,05	0,09	11	0,12

The average value of error in the scale of an image from Table V is m'_{xy} = 10 μm, mean error of heights is m_h = 0,098‰ h.

For the verify of applicability of the results of the SAT for the URM the position coordinates of 75 points were measured by geodetic method and at the same time by the SAT. For 64 points sea levels were measured. The geodetic measuring was considered to be errorless.

Errors of the determined points by the SAT were processed in this set as follows: m_{XY} = 0,05 m, m_h = 0,12 m.

5. Final remarks.

We expect a minor height error during further applications because it was not pointed on the ground but on the head of the monument of the point in measured areas. Considering the relatively small scale of images the stereoscopic pointing was uncertain.

On the basis of existing results I assume that the described method of the creating of a detailed point field shows priorities of it own even for large-scale mapping.

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