FOTEF: Experiences with data snooping in photogrammetric production.

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1. ABSTRACT

The data snooping independent model block adjustment program FOTEF was planned to be a tool for quality control in the Survey Department's photogrammetric production process. Similar results were expected from application of data snooping in photogrammetry as are gained in terrestrial networks for years already (2). Preliminary investigations into the effects of application of statistical testing to the elementary photogrammetric transformations, and to small blocks, were promising (1, 5).
However, at the time FOTEF was presented (8) practical experience with the use of it was very limited.
This paper presents a two year's experience with data snooping in normal photogrammetric production. It furthermore includes the results of some empirical reliability studies and it indicates the way FOTEF can be extended to non-conventional alternative hypothesis testing.

2. FOTEF's CONTRIBUTION TO THE OEEPE GROSS ERROR TEST I

The Survey Department participated in the OEEPE Gross Error Test for two reasons. Firstly it was, of course, an appropriate opportunity to test FOTEF's effectiveness. The programming work hardly finished, it was, however, secondly an excellent test for finally testing the program package itself. Phase I of the Gross Error Test proved data snooping to be the most powerful gross error detection technique. The Delft University of Technology, with its own GPF-program, and the Survey Department, were the only participants cleaning the model blocks using data snooping, and they scored best (4). The results of block MII showed that data snooping gives just slightly better results in regular and well controlled cases. The power of the data snooping technique is more clearly shown by the results of block MI, a poorly controlled and rather irregular block. In such cases data snooping leads to results significantly better than those of other cleaning techniques.

3. DATA SNOOPING IN PHOTOGRAMMETRIC PRODUCTION

FOTEF's error detection procedure consists of two parts: a pre-adjustment search for gross errors, followed by rigourous adjustment and data snooping.
The simple and straight forward step by step error detection strategy of the pre-adjustment programs (2D, 3D) makes the search for real gross errors easy, errors such as identification and point number errors, but also part of the observational errors.
Cleaning the data up to the 250 μm level in XY, and to the 500 μm level in Z, requires 2-3 pre-adjustment runs on the average.
Just to remove the errors that show up clearly, and leave the smaller ones to be detected by data snooping, proves to be the more efficient way to use the pre-adjustment programs.

The Survey Department's standard aerial triangulation process leads on the average to a precision level of the photogrammetric observations given by σ_{xy} = 10 μm and σ_z = 15μm. Furthermore single coverage blocks, with horizontal control points at the borders and strings of vertical control points, crossing the strips at mutual distances of 3-4 baselengths, are common at the Survey Department until now.
A 8-10σ internal reliability level is attainable with these blocks by data snooping.
This means 80-100μm in XY and 120-150μm in Z, which level in general is attained by 4-5 runs of the adjustment and data snooping programs.

Cleaning and adjusting a block, including pre-adjustment error detection, requires on the average 0.25 manhours/model in the 2D, and 0.5 manhours/model in the 3D case. Roughly 70% of the gross errors is found by the pre-adjustment search, which requires just a few minutes per model.

In general it can be stated that FOTEF with its step by step pre-adjustment gross error detection strategy and its final data snooping really facilitates gross error detection and brings aerial triangulation quality control up to a higher standard.
This was indicated already by the OEEPE Gross Error Test. A substantial rise of the number of re-measurements (photogrammetric and terrestrial) in the first period after the introduction of FOTEF formed a second indication. It appeared to be necessary to give the photogrammetrists the possibility of checking model connections on-line by data snooping.
However, may be the first merit of the data snooping method is not an increased but a known quality of the data. The test statistics together with the boundary values and redundancy numbers, as given by FOTEF, really reveal the actual quality of the observations much better.

However, the introduction of the data snooping method does not bring the quality control story to an end. One should realize that by data snooping the quality actually attained is checked up on the quality which is expected to be attainable.
Production asks for a second step: the attuning of the aerial triangulation quality to the quality requirements of the final products.
We felt it was necessary to do further investigations into this subjectarea. Some preliminary results are given in the next chapter.

4. SOME EMPIRICAL STUDIES

FOTEF should be a fast running production program. Therefore it uses a simplified stochastic model, the stochastic properties of both the terrestrial and the photogrammetric observations being described by a diagonal variance-covariance matrix.
Omitting the correlations between the observations was not expected to affect the FOTEF data snooping effectiveness seriously. This, however, had to be checked.
As was already found by Neleman (7), the neglect of correlations between photogrammetric observations affects boundary values to a maximum of about 10%. The consequences of neglecting the correlations between the terrestrial co-ordinates now have been examined too. Planimetric blocks were computed both with FOTEF, and with the GPF-program of the Delft University of Technology, using Baarda's artificial variance-covariance matrix for the control points (3). (Appendix I).
The boundary values of the photogrammetric observations, as given by the two programs, differ hardly. The maximum influence on the boundary values of the control points is found to be about 10% too.

Though a more thorough study, including height, should be made, a tentative conclusion can be that FOTEF's data snooping and internal reliability output is not seriously disturbed by the simplifications of its stochastic model.

The goal of another empirical survey, restricted to planimetry too, was to get a better insight into the effects of non-detected gross errors on the final photogrammetric products, maps or DTM's (9). An erroneous observation leads to erroneous final adjusted co-ordinates, as a result of aerial triangulation. Consequently in mapping, or building up a DTM, at least part of the models is fitted to erroneous control points. And so in the end there will be an area within the block, in which all photogrammetrically determined points are more or less erroneous.
Within this study two regular artificial blocks have been used. (Appendix II). Various gross errors have been inserted subsequently. The results of the computations show:

1. Due to a non-detected gross error in the terrestrial or photogrammetric co-ordinates of a control point, a maximum error in photogrammetrically determined detail points is to be expected of 70% of the magnitude of the non-detected gross error.
2. In case of a gross error in a tie point, this percentage is 30%.
3. Due to an arbitrary non-detected gross error, a maximum error in a distance between two photogrammetrically determined detail points is to be expected of 50% of the magnitude of the non-detected gross error.

Of course these conclusions are only valid in case of regular single coverage blocks, as used for the test computations.

It should be mentioned here that these studies with FOTEF have been performed in close co-operation with the Geodesy Department of the Delft Technical University. Future studies will have to deal with the problems of precision too.

5. NON-CONVENTIONAL ALTERNATIVE HYPOTHESIS TESTING

Photogrammetric observations, as well as co-ordinates of control points, can be affected by systematic errors. The technique mostly used to tackle this problem is self calibration.
A more careful approach, however, was given by Molenaar (6), who suggested to base the decision whether or not to compensate for systematic errors upon non-conventional alternative hypothesis testing.
FOTEF is planned to be extended this way. Non-conventional alternative hypothesis testing is expected to bring a valuable refinement of FOTEF's error detection facilities.
The extension can be performed relatively simply, as the decomposed non-reduced normal equations still are available (8):

$$(U^T U)\Delta Y = (A^T P)\Delta X$$

According to Baarda (2) a non-conventional alternative hypothesis H_a is represented by a vector H:

$$\widetilde{\nabla X} = H.\nabla$$

Parameter ∇ acts here as a kind of scale parameter. Testing requires the computation of test statistic w:

$$w = \frac{H^T P \varepsilon}{\sigma \sqrt{N}}$$

In this formula the factor N is given by:

$$\begin{aligned} N &= H^T \left[P - PA(U^T U)^{-1} A^T P \right] H = \\ &= H^T PH - H^T PA(U^{-1} U^{-1^T}) A^T PH = \\ &= H^T PH - (H^T PAU^{-1}).(H^T PAU^{-1})^T = \\ &= H^T PH - WW^T \end{aligned}$$

Values WW^T can be calculated by a forward substitution step, according to Choleski's method:

$$U^T W^T = A^T PH$$

So the computational effort required for testing one non-conventional alternative hypothesis is just one forward substitution step.
If the alternative hypothesis is not rejected, the magnitude of the complex of errors, modeled by vector H, can be estimated by

$$\nabla = \frac{W}{\sqrt{N}}$$

It is intended to provide FOTEF with a standard set of non-conventional alternative hypotheses, describing possible deformations (block-invariant and strip-invariant) of the photogrammetric models. Besides it is intended to offer the user the opportunity to define and test hypotheses describing deformations of clusters of control points.

6. CONCLUSIONS

1. Data snooping facilitates gross error detection and brings aerial triangulation quality control up to a higher standard, as the actual quality of the observations is much better revealed.
2. A tentative conclusion, based upon experiences (e.g. OEEPE test) and some empirical studies, is that a rigourous simplification of the stochastic model does not seriously disturb a data snooping independent model adjustment program's error detection effectiveness.
3. For regular single coverage blocks holds:
   - The maximum influence of a non-detected erroneous observation of a control point on photogrammetric detail point determination is about 70% the magnitude of the non-detected gross error.
   - This percentage is 30% in case of errors in tie points.
   - Distances between photogrammetrically determined detail points are affected to a maximum of about 50% of the magnitude of an arbitrary non-detected gross error.
4. The program package FOTEF can be extended to non-conventional alternative hypothesis testing relatively simply. This is expected to bring a further refinement of its error detection facilities.

REFERENCES

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APPENDIX I

The influence of correlations between terrestrial co-ordinates on boundary values.

A regular single coverage block has been used, with an image scale 1:4000, and standard deviations of model point co-ordinates 10 μm (figure 1)

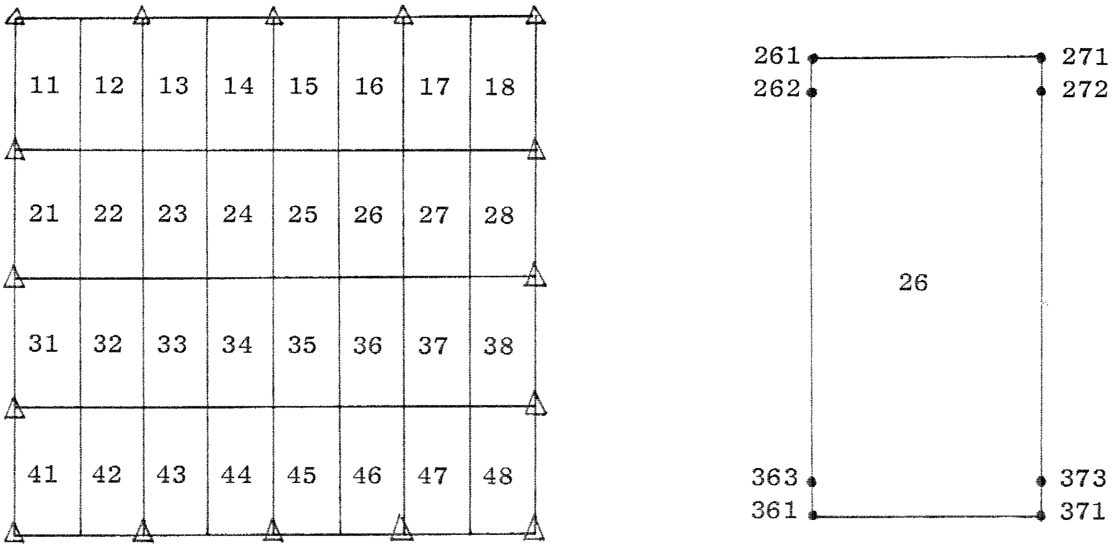

figure 1. Test block.

The test block has been computed twice:

- Using FOTEF and a diagonal variance-covariance matrix F, with standard deviations of ground control point co-ordinates 2 cm.
- Using GPF and Baarda's artificial variance-covariance matrix G (3), with parameters C_o, C_1 set to: $C_o = 0$, $C_1 = 9,2$.

In both cases the variance-covariance matrices were defined within a so-called (a)-system. Setting parameter $c_1 = 9.2$, the maximum eigenvalue λ, following from $|F - \lambda G| = 0$, is 1.

The results of the computations are shown in the table below.

point number	observ. type	model number	bound. value F	bound. value G
111	model	11	29	32
211	model	11	26	27
121	model	11	29	30
122	model	11	29	30
223	model	11	30	30
221	model	11	25	25
141	model	14	29	29
142	model	14	29	29
243	model	14	30	30
241	model	14	25	25
151	model	14	25	25
152	model	14	30	30
253	model	14	29	29
251	model	14	25	25
211	model	21	26	28
311	model	21	26	28
221	model	21	25	25
222	model	21	30	30
323	model	21	30	30
321	model	21	25	25
241	model	24	25	25
242	model	24	30	30
343	model	24	30	30
341	model	24	25	25
251	model	24	25	25
252	model	24	30	30
353	model	24	30	30
351	model	24	25	25
111	terr		29	32
131	terr		22	24
151	terr		22	23
211	terr		22	24
311	terr		22	25

Key:
column 4: boundary values, using the diagonal matrix F.
column 5: boundary values, using the Baarda matrix G.

APPENDIX II

The influence of non-detected gross errors on photogrammetric detail point determination.

Two regular single coverage blocks have been used, with an image scale 1:5000, standard deviations of ground control point co-ordinates 5 cm and standard deviations of model point co-ordinates 10 μm (see figure 2, 3).

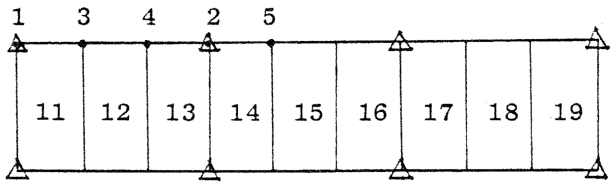

Figure 2. Block I.

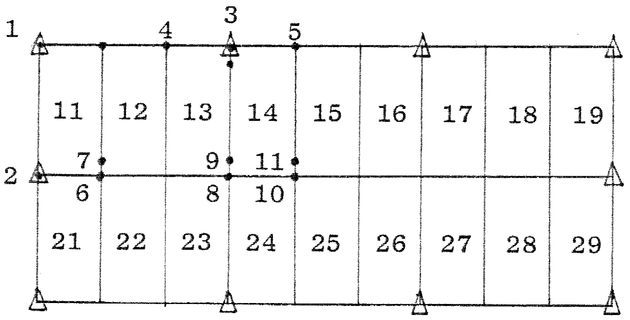

Figure 3. Block II.

Several gross errors have been inserted subsequently. The results of the computations with FOTEF are given in the table below.

Block nr.	Error nr.	Number models	Model/ ground	Model nr.	Nabla	Point	Dist	Dist	Point prop	Dist prop	Dist prop
1	1	1 + T	TERR		47	32.2	11.6	14.9	0.69	0.25	0.32
2	1	1 + T	TERR		46	31.0	11.4	14.8	0.67	0.25	0.32
1	2	2 + T	TERR		36	24.3	8.8	10.9	0.68	0.24	0.30
2	2	2 + T	TERR		35	22.6	7.7	8.8	0.65	0.22	0.25
2	3	2 + T	TERR		36	25.8	7.0	10.7	0.72	0.19	0.30
1	1	1 + T	MOD	11	47	32.2	11.6	14.9	0.69	0.25	0.32
2	1	1 + T	MOD	11	46	31.0	11.4	14.8	0.67	0.25	0.32
1	2	2 + T	MOD	13	34	18.4	7.0	15.6	0.54	0.21	0.46
2	2	2 + T	MOD	11	36	20.3	7.3	17.8	0.56	0.20	0.49
2	3	2 + T	MOD	13	34	19.3	7.3	10.7	0.57	0.21	0.31
1	3	2	MOD	11	39	9.4	3.7	15.5	0.24	0.09	0.40
1	4	2	MOD	12	39	10.1	4.0	15.2	0.26	0.10	0.39
1	5	2	MOD	14	38	9.5	3.7	14.6	0.25	0.10	0.38
2	4	2	MOD	12	38	9.7	3.8	14.4	0.26	0.10	0.38
2	5	2	MOD	14	38	9.4	3.7	14.2	0.25	0.10	0.37
2	12	2	MOD	13	39	8.1	3.3	16.2	0.21	0.08	0.42
2	7	2	MOD	11	38	8.1	3.3	14.5	0.21	0.09	0.38
2	9	2	MOD	13	37	6.7	2.7	13.2	0.18	0.07	0.36
2	11	2	MOD	14	37	7.2	3.7	14.3	0.19	0.10	0.39
2	6	4	MOD	11	32	9.4	3.9	14.5	0.29	0.12	0.45
2	8	4	MOD	13	31	8.9	3.5	12.9	0.29	0.11	0.42
2	8	4	MOD	14	31	9.6	3.7	13.8	0.31	0.12	0.45

Key:

column 1	: Block number.
column 2	: Point number of the erroneous point; it corresponds to the number in the figure.
column 3	: Number of models in which the erroneous point has been measured.
column 4	: Error type: terrestrial (TERR) or photogrammetric (MOD).
column 5	: Model number of the model in which the error was inserted.
column 6	: Boundary value of the erroneous observation.
column 7	: Maximum influence of an error of the magnitude of the boundary value on adjusted terrain coordinates.
column 8	: Maximum influence on a distance between two points measured in the same model.
column 9	: Maximum influence on a distance between two points measured in different models.
column 10-12	: The same information as given in column 7-9 but now proportional to the size of the error inserted.