Experiences in Blunder Detection for Aerial Triangulation

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1. Introduction

Any error which can happen will happen. It seems, this is also the case in data collection for bundle block adjustment. Usual large blunders can be detected also without some special procedures, but it is time consuming. Smaller blunders sometimes cannot be detected without special procedures. But also with data snooping and robust estimators the registration of one object point with different point numbers in different photos cannot be detected.
The method for error detection in bundle block adjustment realized in the University Hannover and the experience with this is described.

2. Methods for Blunder Detection

Blunder detection must be done step by step, starting with large blunders. Very large blunders cannot be detected by bundle block adjustment because the computation will not converge. The online-triangulation is the optimal method for data collection, blunders can be seen during measurement and the measurement can be repeated. By this reason, the error limit can be lower than in the case of an offline test, where measurements usual are deleted.
Two different statistical tests are used for blunder detection:

A. DATA SNOOPING

The size of the residuals of a block adjustment are tested for the exceeding of a critical value, which is defined by a standard deviation and a probability level. But the size of a residual is not identical to the size of an existing blunder, only a part of this will be represented.

$$v_i = - r_i \cdot \varepsilon_i$$

v_i = residual
ε_i = true error
r_i = partial redundance

The partial redundance - the ratio of the residual to the true error - is depending upon the geometry of the unit to be adjusted.

$r_i = (\underline{Q}_{vv}\ \underline{P}_{ee})_{ii}$

$\underline{Q}_{vv}$ = cofactor matrix of observations
$\underline{P}_{ee}$ = weight matrix of observations

$\underline{Q}_{vv} = \underline{Q}_{ee} - \underline{A} \cdot \underline{N}^{-1} \cdot \underline{A}^T$

$\underline{Q}_{ee}$ = cofactor matrix of unknowns
$\underline{N}$ = normal equation matrix
$\underline{A}$ = matrix of coefficients

$$w_i = \frac{v_i \cdot \sqrt{p_i}}{\sqrt{r_i} \cdot \sigma_o}$$

w_i = normed corrections
p_i = weight of observation
σ_o = standard deviation of unit weight

The normed corrections w_i are normal distributed with the expectation value 0.0 and the standard deviation 1.0.
They are compared with the value of the t-distribution corresponding a chosen probability level.

advantages of the data snooping

The data snooping is a sensitive method with a particular advantage in the case of a wide range of the partial redundance.

disadvantage of the data snooping

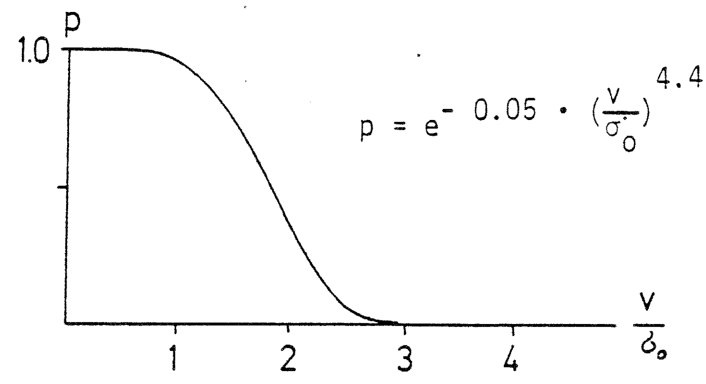
The standard deviation of unit weight σ_o is influenced by blunders. Especially in the case of a small redundance it cannot be estimated accurate enough. An a posteriori value must be used, which will influence the test.
The weight of the observation must be known more accurate than for the adjustment. For example, the difference in the weight of photo coordinates depending upon the location in the photo (centre or corner) can reach a ratio of 1 : 1.7. This has no remarkable effect to the adjustment (Jacobsen 1980) but it is important for the test.
The residuals are correlated - a blunder has an influence also to other points. So usual only one blunder can be detected in one adjustment.
The cofactor matrix of the observations must be computed. This is time consuming because the normal equation matrix must be inverted. This is not necessary for the resolution of an adjustment.
The adjustment must be repeated without the detected blunder.

B. ROBUST ESTIMATORS

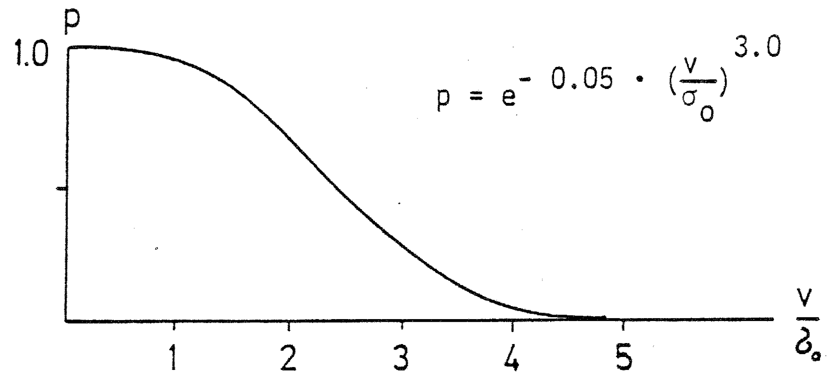
By the method of the robust estimators, the weight of the observations is modified iteratively. In the program BLUH, the weight functions published by Krarup, Juhl, Kubik 1980 are used as default functions. After convergence of the usual adjustment, the first weight function is used, later the second one. A faster reduction of the weight with growing residuals is necessary during the first iterations with robust estimators, because of the influence of the standard deviation of unit weight to the weight function.

advantage of the robust estimators

More than one blunder can be detected in the same adjustment.



default weight
functions for
robust estimators



If the blunder(s) is not caused by incorrect point transfer, the adjustment with robust estimators can represent the final result. The normal equation matrix must not be inverted, this will save time for computation.

disadvantage of the robust estimators

If the range of the partial redundance is very large, smaller blunders in observations with small partial redundance cannot be detected. Especially for error detection by relative orientation the robust estimators can lead to wrong results.

3. Blunder Detection by STEPS

The robust estimators and the data snooping can only be used if the adjustment will have a convergence. By this reason, very large blunders have to be searched by other procedures. In the program system BLUH this will be done by combined strip computation for the determination of approximate orientation data.
The computation of mean values of photo coordinates usual will give only information about pointing accuracy.
The Helmert transformation of neighboured photos can check errors in point numbering (same point number for different points) and different photo coordinate systems of neighboured photos.
The computation of the relative orientation will be tested by data snooping with automatic elimination of blunders. Because of the large differences in the partial redundance, the method of robust estimators cannot be used. The number of unknowns is limited, so the time for computation is negligible.

blunder detection by combined strips

1. mean values of photo coordinates (pointing accuracy)

2. Helmert transformation of neighboured photos (errors in photo coordinate system, errors in point numbering)

3. relative orientation (exact test for y-coordinates)

4. Helmert transformation of neighboured models (check for point transfer in the strip)

5. Helmert transformation of neighboured strips (rough check for point transfer from strip to strip)

   3-dimensional transformation of a strip to control points and points from strip before (check for point transfer from strip to strip, check of control points)

6. Helmert transformation of internal block system to control points (rough check of control points)

two dimensional	three dimensional

With the data from relative orientation, model coordinates are computed. The model coordinates are transformed by Helmert transformation to the strip built up to now. This will check the point transfer between neighboured photos and, in the case of 80 % endlap, the point transfer also to the photo before.
Depending upon the number of vertical control points and the sidelap, the following tranformations can be done twodimensional or more accurate, three dimensional. If enough vertical control points are available or in the case of 60 % sidelap the strip can be transformed three dimensional to control points and the points from strips transformed before. This will be checked by data snooping, but the power of the test is not the same

like in the block adjustment because of the not so accurate strip computation. In the case of a small number of vertical control points and less than 60 % sidelap, the strips are transformed two dimensional together and the so created internal block system will be transformed two dimensional to the control points. The orientations of the strips are defined by the direction of the first photo in each strip. The nadir angle will have an influence to the x-y-coordinates of the strip and this limits the possibility of blunder detection.
With both methods of transformation the point transfer from strip to strip, the point numbering (same point number for different points) and the control points are checked.
The first check for blunders by block computation with combined strips is partially limited, partially sensitive. The connection of photos to a strip can be tested more accurate than the strip connection and transformation to control points. In any case, the following bundle block adjustment will converge and the robust estimators, described before, can be used. The data snooping has been shown as not optimal for bundle block adjustment.
It is not possible to check with the preceding procedures whether the same point number was used for identical points. This will be done after block adjustment by the computation of the distance from each point to each other. If a distance is smaller than a limit, this indicates an error in point numbering. Such error will have no direct effect to the block but the geometry will be weakened.

4. Experiences

The number of blunders can be very different from block to block. The best results are achieved with signalized points and measurement with online triangulation. These blocks can be completly withouth blunders (Jacobsen 1984). The highest percentage of blunders appears in not signalized blocks, measured with mono comparators, not optimal photo quality and photos from different photo flights.
The blunder detection by combined strips is not necessary for blocks measured by online triangulation because these tests are made during measurement. In other blocks 70 % to 80 % of the blunders are detected before start of the bundle block adjustment. The limit of acceptance for the data snooping in the relative orientation is not easy to be found. The number of photo points in a model is too small to estimate the standard deviation of unit weight and the a priori standard deviation cannot be estimated very accurate if the photo quality is not sufficiant. Also the dependence of the accuracy of a photo coordinate from the location in the photo is usual not known very well, because it is different from camera to camera and depending upon the condition of the atmosphere. A size of the normed correction corresponding to a probability level of 0.001 (under assumption of weight = 1. for each photo point) has been found as insufficient. The limit of the normed correction should not be smaller than 4.0.

There is no need of the fitting of the strips by adjustment. Only very large blunders should be excluded by reason of the results of strip transformation. Medium and smaller blunders of the strip connection should be checked by block adjustment.
The method of robust estimators has been found as a very powerful test. A high number of blunders can be found in one program run. But also this method has its limits. If medium and small blunders are present, the number of iterations with weight manipulation must be raised. At first

medium blunders will have an influence to the standard deviation of unit weight, which will be used in the weight formula. So the small blunders will not get a small weight.
A weight with the value 0.0 or near to 0.0 will cause some numerical problems in the adjustment. There are two possibilities, observations with extreme small weights can be eliminated or the value of the weight can be raised up to a minimum. The elimination of observations has been found as disadvantageous. During the first iterations also correct measurements can be influenced by neighboured blunders and can have residuals which will cause weights near to 0.0. The residuals of these correct measurements will become smaller during the next iterations and they will have again an influence to the adjustment. Depending upon the word length of the computer, the lower limit of the weight will be 10^{-8} or 10^{-10}.
Not in any case, the adjustment with robust estimators will represent the final result. Very often, errors in point transfer from strip to strip will happen. In this case, all measurements in one strip will get a small weight. That means, these measurements are also not used for the connection of the photos in this strip. The adjustment must be repeated with a stripwise separation of the observations. The same can happen with control points.
If a point is measured only in two photos, it is not possible to detect blunders in the direction of the base (x-direction). In the y-direction blunders can be detected but not located. One photo coordinate will get a small weight, but it is accidental which. The same happens with blunders in x-direction and measurement of a point in only three photos. The three rays will have three intersections and it is not possible to decide which is correct. The received object coordinates of these points cannot be used.
The weight functions described before, could be used in any case with one exception - a large block with photos from seven photo flights with a difference in flight time of 5 years and photo scales from 1 : 140 000 to 1 : 30 000 (see appending location of the photos in the block) was prepared and measured by students of geography without any experience, at a stereo comparator. The number of blunders was 1.5 %. Especially the connection of strips with different flight time and photo scale caused problems. The connection of the strips was neutralized by the default weight functions of the robust estimators and the iterations diverged. It was possible to compute the block adjustment with changed weight functions. But without robust estimators and precomputation with combined strips it was nearly impossible to solve the problem.
In 80 % of the larger blocks, measured without online triangulation, the use of different point numbers for identical points in different photos was detected after block adjustment by computation of the distances between object points.

5. Conclusion

The described tests represent a usable combination of tests with a good support of the program user. In general the user must not have a good theoretical background, but he must have some information about the meaning of the results. Each observation, which was eliminated by the program or which influence was reduced by a small weight, should be checked, because the geometry of the block is weakened and sometimes photos should be remeasured to prevent negative effects.

In general, the redundance must be large enough to detect and locate blunders. Blocks with more than minimum endlap and sidelap should be prefered. In the case of computer supported data acquisition with analytical plotters, a higher overlap will raise the time for measurement not so much. The accuracy of the object points and more important, the reliability, will be raised.
The smallest percentage of blunders was detected in blocks measured with online triangulation at analytical plotters. The number of blunders was raised by data collection at analytical plotters without online check and more in the case of stereo comparators and again more in the case of mono comparators. The percentage of blunders also was strongly depending upon the experience of the operator, the photo quality and the photographed object. The differences have been so large, that it is not possible to give a rule of thumb of the percentage of blunders.

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block with problems in blunder detection