DEFORMATION ANALYSIS USING THE RESULTS OF COMBINED ADJUSTMENTS

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0 Summary

Deformations can be detected by analysing the results of bundleblock adjustments of two epochs. A deformation analysis program is presented and its connection to the BINGO program system is shown. One application is shown.

Zusammenfassung

Deformationsanalysen können basierend auf Ergebnissen von Bündelblockausgleichungen einzelner Beobachtungsepochen durchgeführt werden. Ein Analyseprogramm wird in seiner Funktion und Verbindung zum Programmsystem BINGO beschrieben. Ein Anwendungsbeispiel wird gegeben.

1 Introduction

Using geodetic networks to find out deformations of objects is a well known technic, but this kind of observation has technical and economical limits. The use of photogrammetry makes the monitoring of objects very flexible with respect to measurement speed, number of object points and repeating rate. For that reason a program is developped, optimized for this special data source. It processes information obtained by bundle block adjustment.

2 Adjustment of photogrammetric data

In a photogrammetric adjustment usually a big amount of data (observations, unknowns) has to be handled. Depending on the main application, several data reduction and optimization strategies can take place. A combined adjustment program like BINGO processes photogrammetric data and other observations, e.g. distances, simultaneous and is therefore a optimal part of a deformation analysis program system. For combined adjustments sparse matrices and profile minimization are recommended /1/. For deformation analysis it is necessary to be able to access all parts of the cofactor matrix of the unknowns.

3 Base formula for deformation analysis

At first some basic conditions should be fixed to guarantee a operational solution.

- Each epoch is **adjusted seperatly**. A combined adjustment of the epochs is not necessary. The analysis is done afterwards. The amount of data for a multi-epoch adjustment would be to big for a economic solution.
- The adjustment has to be performed in a **S-system**, i.e. the introduced control information must not influence the geometry of the network (e.g. at most 7 fixed coordinates in a 3-d network).
- **Changes** in point **configuration** and plan of **observations** are possible. The analyse can done even if points or observations are added or left out.

For each epoch i the adjustment gives

$$\begin{array}{ll} x_i & \text{vector of the unknowns (coordinates etc)} \\ Q_{xxi} & \text{cofactor matrix of the unknowns} \\ s_{0i}^2 & \text{empirical variance of weight unit} \end{array} \qquad (1)$$

The variance of weight units have to be the same in the epochs. This can be tested by using the quotient s_{01}^2/s_{02}^2, which is F-distributed. If the variances are different, the adjustments have to be repeated with modified weights derived from variance component estimation /2/.

The datum for the coordinates must be unique for both epochs. The coordinates and the cofactor matrices are transformed by a S-transformation based on all fixed points. This leads to identical results as minimizing the partial trace of this point in a adjustment. All additional unknowns, as photo orientations etc, can remain in the vectors of unknowns and the cofactor matrices without interfering the analysis. The S-matrix is computed as

$$S = I - G\,(G^T E_i\, G)^{-1} G^T E_i \qquad (2)$$

where I : unity matrix

G: coefficients for transformation parameters

E_i: Diagonal matrix, elements equals 1, if fixed point, otherwise 0

For detailed explanation see /2/, /4/. The transformation then is

$$\begin{array}{ll} x_i' & = S\,x \\ Q_{xxi}' & = S\,Q_{xxi}'\,S^T \end{array} \qquad (3)$$

and the resulting differences between the epochs are

$$\begin{array}{ll} d & = x_2 - x_1 \\ Q_{dd} & = Q_{x1x1} + Q_{x2x2}\;. \end{array} \qquad (4)$$

As PELZER /3/ has shown, the quotient

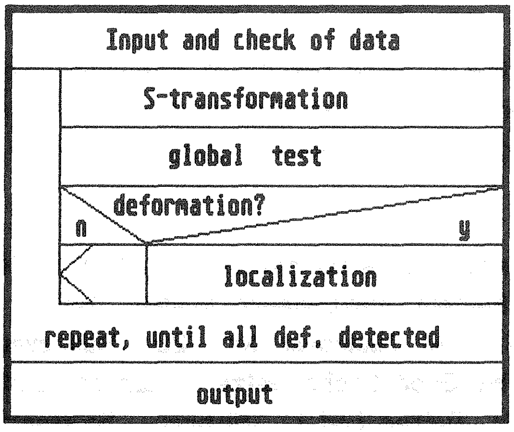
$$F = \frac{d^T Q_{dd}\, d}{s_0^2\, h} \qquad (5)$$

is a F-distributed global testvalue. If the test indicates, i.e. F is greater than the correspondent value of the F-distribution, a deformation is anywhere in the network. For locating the moved point, step by step each fixed point is treated as changed. Therefore the elements of this point in equation (2) are set to zero and the steps (2) to (4) are performed again. The factor $d^T Q_{dd} d$ becomes a minimum when the moved point is left out. The computation is repeated, starting at (2), until no further deformation is detectable.

4 Realization

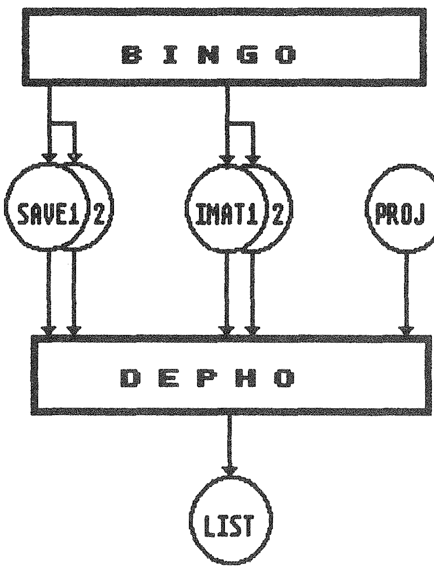
The presented software for deformation analysis consists mainly of two parts:

- **BINGO** standard program system for bundleblock adjustments and
- **DEPHO** analysing program.



The program system BINGO can be used nearly unchanged. A detailed description is given in /1/. The program DEPHO is realized according to the formulas given in the preceding paragraph, Fig. 1 .

Fig. 1 structure of program DEPHO



For each epoch DEPHO needs a SAVE-file, including the unknowns of the adjustment and some other information, and the file IMAT, which contains the the cofactor matrix of the unknowns. The names of connected files are listed in the project file PROJ. Results of the analysis, mainly lists of fixed and moved points are given in the listfile LIST, Fig. 2.

Fig. 2 connections between BINGO and DEPHO

5 Practical results

The gotic church Michaeliskirche in Lueneburg is the monitored object. It is build upon a salt dome on a very irregular underground, which makes it impossible to predict movements. One observation epoch is done each year since 1984. 103 points are marked on the walls and columns. Because of the columns the visibility conditions are poor and so about 90 photographs are necessary for a equal coverage . In addition 400 geodetic measurements and other constraints are introduced in the adjustment. Approximatly 1100 unknowns are computed out of 3100 observations. The mean accuracy for coordinates is 0.4 mm. Using DEPHO each epoch is compared with the preceding one and the base epoch. Deformations of 1 up to 4 mm were detected.

6 Conclusion

Deformation analysis can be done very effective by using results of combined adjustments of photogrammetric and geodetic data. Special optimizations have to be done for a effective handling of the big amount of data. They will be included in program DEPHO.

7 Literature

/1/ Kruck, E. Lösung großer Gleichungssysteme für photogrammetrische Blockausgleichungen mit erweitertem funktionalem Modell, Wiss. Arb. d. Fachr. Verm.wesen d. Univ. Hannover Nr. 128, Hannover, 1983

/2/ Niemeier, W. Deformationsanalyse in: Geodätische Netze in Landes- und Ingenieurvermessung II , H. Pelzer (ed.), Wittwer, Stuttgart, 1985

/3/ Pelzer, H. Zur Analyse geodätischer Deformationsmessungen, Dtsch. Geodät. Komm., Ser. C, 164, 1971

/4/ Illner, I. Freie Netze und S-Transformation, AVN, vol 90, 1983