AERIAL TRIANGULATION BY ANALYTICAL PLOTTER

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ABSTRACT

For aerial triangulation a software package utilizing the analytical plotter has been developed in the Institute of Photogrammetry of Helsinki University of Technology. The programs for data acquisition and bundle block adjustment have been installed in a PDP 11/23 microcomputer which is connected to a Kern DSR-1 analytical plotter.

Special attention is paid to making the photogrammetric determination reliable and to detecting all gross errors from the data as soon as possible. Under computer control the operator can improve the geometry of the system. Data snooping statistics according to Baarda are used in every step (inner orientation, triplet formation, absolute orientation, polynomial strip adjustment, bundle block adjustment) to detect gross errors.

The data acquisition and the bundle adjustment programs use the same data base. So it is easy to start a bundle adjustment whenever the operator wants to.

The system can treat 500 photos, more than 35 000 points, and 2 500 points per model.

1. INTRODUCTION

Analytical plotters are ideal instruments for photogrammetric triangulation purposes, as they quarantee sufficient accuracy and are in principle easy to program to utilize automation and to carry quality control during the measuring process. However, today we are still quite far from a complete triangulation system for analytical plotters as working stations.

The Institute of Photogrammetry at the Helsinki University of Technology procured its Kern DSR 1 analytical plotter at the end of 1981 e.g. in order to study the suitability of different strategies of online triangulation for it. In the following year many of the philosophies were under discussion and research. The most important finding from these studies was the fact that the current analytical plotters are equipped with mini- or microcomputers! This means it is not yet possible to implement rigorous almost real-time block or sub-block adjustments on them without making the operator's life a nightmare. This still prevails, even if the most efficient recursive least squares estimation techniques were applied. To make the process really operational (response time 1 - 2 sec.) a 32-bit superminicomputer equipped with an array processor is needed. Keeping this in mind and not forgetting all the ergonomic aspects a system of this kind must fulfil, it was decided to apply a quite conservative strategy in realizing the system.

The implementation of the triangulation system for the DSR 1 was started at the end of 1982. It now comprises the programs for data acquisition, bundle block adjustment as well as all routines for managing the data, i.e. the data base.

2. BASIC CONCEPT OF THE SYSTEM

The triangulation system consists of two independent parts, the measuring system and the bundle adjustment which share a common data base (Fig. 1).

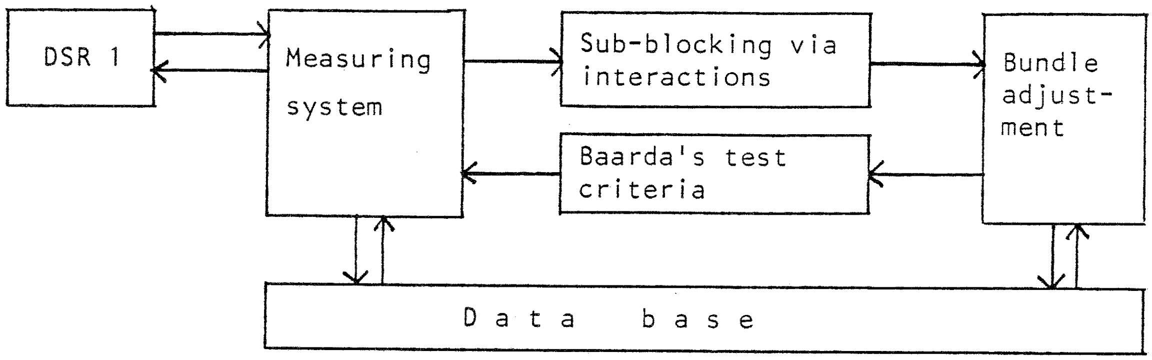

Fig. 1. The triangulation system implemented in the DSR 1.

The communication between the two programs happens indirectly via the data base and directly with the help of two small routines. The block adjustment can be started up whenever wanted by choosing the data for it interactively (sub-blocking). From the bundle block adjustment a feedback is received in the form of weight coefficients of residuals (q_{vv} values). They can be utilized in an interactive routine which computes the test criteria (t-test values), thus making it possible e.g. to evaluate the necessity of remeasurements.

Apart from some simple checkings Baarda's data snooping is the primary means of checking gross errors. The data snooping is adapted in the following least squares computations: inner orientation, relative orientation, triplet formation, all similarity transformations, polynomial strip adjustment and bundle block adjustment. Interaction is always used when making final decisions concerning the detected gross errors.

3. DATA BASE

The data base which is totally updated after each measurement consists of the following items (capacity in the PDP-11/23 given in parentheses):

- points to be adjusted (4 500)
- photos (500)
- strips (50)
- blocks (3)
- cameras (200)
- model set up (500 points)
- points to be intersected after the final bundle block adjustment (32 767; 2000 per model)
- point groups (30)

The observations are stored on point records thus making the bundle block adjustment much more efficient. Point group means a group of points having the same measuring and adjustment parameters (e.g. pointing precision, accuracy of geodesy, numbering scheme etc.).

The text file which makes the system a multi-lingual system can also be considered as a part of the data base. All outputs and interactions made by the system happen via this file.

4. MEASURING SYSTEM

The operationality is the main criterion a system of this kind should fulfil. The software must flexibly support all or at least nearly all the functions which might occur in the operator's mind during the measuring procedure. Further, it must be capable of taking care of all possible error situations. Otherwise it may happen that the computer support impedes flexible measuring or might even make it impossible. Thus a large amount of checking and much interaction are needed. As only a limited capacity minicomputer is available and all these operational aspects take a huge amount of the core, very little is left for the numeric processing itself, although the programs are very heavily overlaid.

4.1 MAIN MENU OF THE MEASURING PROGRAM

The measuring system has the following main menu:

- Initiate project. This is needed only when initiating a new project.
- Continue process. It makes the program continue from just the point where the system previously paused.
- Continue process, but renew the inner orientation. This is applied when the photos were for some reason taken away from the photo stages.
- Start new strip. This is used when activating a new strip.
- Renew last model totally. This is needed when because of a fatal error situation, one wants to make all measurements of the current model again.
- Make remeasurements. This makes it possible to remeasure or observe additional points for any model already in the data base.
- Edit data base. This activates the data base editor.
- Start block adjustment. This chains to the bundle block adjustment program.
- Analyze results of block adjustment. This performs a search for gross errors after the bundle block adjustment and makes possible remeasuring of the erroneous points.

4.2 MEASURING STRATEGY

The normal measuring procedure is very straightforward. The operator observes the block strip by strip in any order he wants by performing successive inner orientations and measurements on models, whose parameters are all the time being updated. After each pointing there are the following functions:

1^c Check on differences for points already measured.

2^c Updating of parameters of relative orientation (first model in strip) or triplet formation (other models).

3^c Updating of parameters of similarity transformation between model and object, if object coordinates of the observed point are known (control point, tie point from the previous strip or model etc.).

4^c Updating of the total data base. Therefore no measurements are lost whatever happens during the measuring process e.g. a power cut, if the disc is not scratched.

There have been suggestions for sliding a e.g. 3 x 3 sub-block through the whole block (Grün / 3 /). However, a system of this kind, although ideal for gross error detection, is operationally quite cumbersome (especially in irregular situations) and also computationally too heavy for a minicomputer. In the system in question one can include sub-blocks of e.g. 3 x 3 photos in the bundle adjustment whenever one wants. This strategy has not yet shown its superiority in practice except in some very complicated error situations.

When the measurement of a model is finished, gross error detection is always automatically performed. All the q_{vv} values for model formation and similarity transformation between the model and the object are computed and the corresponding observations tested. Also a polynomial adjustment with gross error detection is performed to detect small gross errors in the object coordinates. If some errors are found, all necessary remeasurements and editing are made.

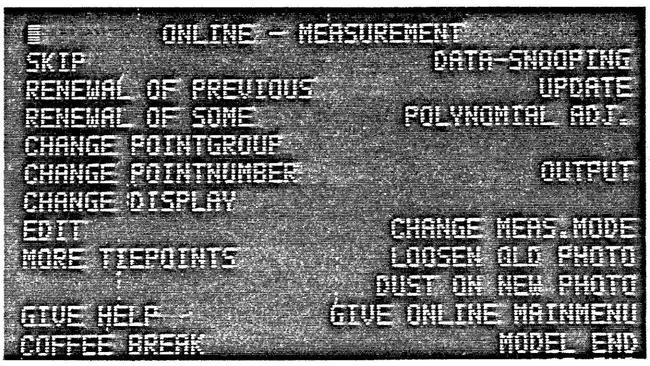

Fig. 2. The menu displayed on the operator's control panel while the operator is pointing.

While pointing, the operator has the menu (Fig. 2) in front of him located on the DSR 1 operator's control panel. There he can choose any time the function he wants by pressing the corresponding key. E.g. by pressing the key "polynomial adjustment" the operator temporarily activates polynomial strip adjustment, although the model is not yet finished.

4.3 AUTOMATION OF MEASURING

There are two types of automation. Firstly the automatic movement to points to be observed and secondly their automatic numbering.

The automatic movement from point to point is carried out as completely as possible. When initiating the project the operator tells the system what kind of point distribution will be used. While measuring the program automatically creates that point distribution.

As mentioned above the transformation parameters between model and object are constantly updated. Therefore the program permits the finding of every possible point on the model from the data base as soon as at least two points are observed from the strip. Thus all control points and tie points measured in the earlier strips are easy to measure. Of course when measuring tie points on the model to be connected, the operator has to do the pointing only in the new photo, unless he presses either of the menu keys "loosen old photo" or "dust on new photo" (Fig. 2).

For automatic point numbering there are numbering schemes of different types and point grouping strategy in use. Thus if the operator does not want to, he is very seldom forced to do manual point numbering. An automatic system of this kind is indeed practically free of gross errors which easily occur when typing point numbers in.

4.4 UPDATING OF PARAMETERS

As mentioned above, all necessary unknown parameters are updated in real-time. The transformations updated are relative orientation based on the coplanarity condition or triplet formation based on the six-parameter solution (Kratky / 5 /), and in addition the seven-parameter similarity transformation based on the simultaneous solution. The updating is normally after the sixth observation on the model based on the direct editing of the Cholesky factor (Inkilä / 4 /). If any malfunction of the updating due to the non-linearity is suspected the operator can press the menu key "update" (Fig. 2). Then the parameters are updated by forming the normal equations and thus performing full computation of each transformation. The computation of all parameters by updating directly the Cholesky factor takes only a fraction of a second.

4.5 QUALITY CONTROL

One important goal for a measuring system is to enable the control of the observations quality to be carried out as early as possible and also to direct the operator to improve the geometric quality of his work. In the system in question the quality of the model is checked by computing the reliability numbers of Baarda's theory. This system is of course limited when speaking of improving the quality of the total block, because the operator is always working only on a very small subarea of it. The gross errors are always detected by computing the standard errors of the residuals and by using the t-test, if δ_0 of the adjustment does not deviate from the previously computed ones significantly. If it deviates, the normal distribution and the "true" δ_0 are used. (Cf. Baarda /1/, /2/.)

The menu shown in Fig. 3 is displayed on the operator's panel when a gross error is detected.

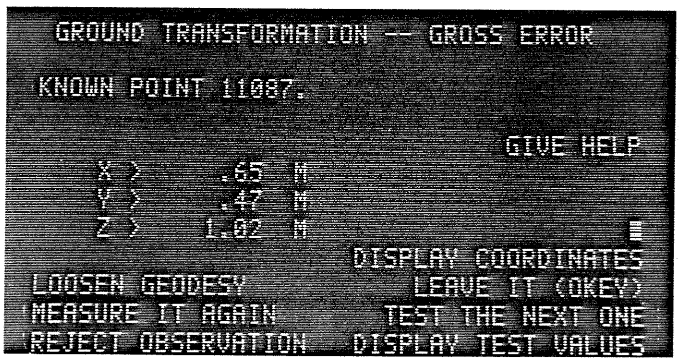

Fig. 3. The menu displayed on the operator's control panel when a gross error is detected.

4.6. SOME ASPECTS OF IMPROVING THE OPERATIONALITY

The system uses a lot of menus when communicating with the user. These are displayed on either the operator's panel of the DSR 1 or the screen of the terminal. Also a strategy for giving advice to the user is always heavily incorporated.

One special feature is the point grouping capability which means that one can divide points of different types into different groups and handle each of them in its own way. The menu for generating the point groups is visible in Fig. 4.

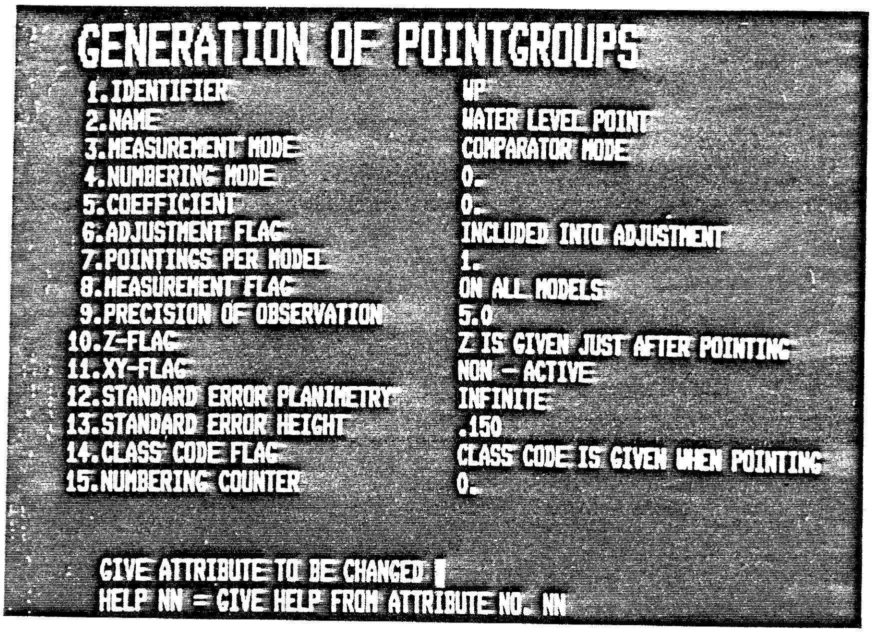

Fig. 4. The menu for generating point groups, displayed on the screen of the terminal.

5. BUNDLE BLOCK ADJUSTMENT

The block adjustment program has been developed to support the online measurements easily whenever so wanted. It can also be used as an independent program, and e.g. it is currently being installed on a 32 bit MV-6000 computer of the Data General.

The support for the data acquisition program is quite successful. To start a bundle adjustment whenever required takes only 2 - 3 sec. and one may choose a sub-block of any kind in the adjustment. If the sub-block consists of too few control points, one can, with the help of graphics, interactively choose temporary control points in the adjustment. After the adjustment the q_{vv} values are available for an interactive program for considering the need of remeasurements and other editings.

The main characteristics of the bundle block adjustment are following (Sarjakoski / 6 /):

- Automatic minimization of the bandwidth by a slightly modified Gibbs-Poole-Stockmeyer algorithm.
- Solution of the reduced normal equations by the Gaussian elimination utilizing the hyperrows of six single rows.
- Computation of the inverse of the reduced normal equations.
- Computation of the 3 x 3 weight coefficient matrices of each object point.
- Computation of the weight coefficients of all residuals.
- Use of additional parameters applying different strategies.

The time needed for computing the q_{vv} values (and of course the interesting parts of the inverse) is about twice the time needed for one iteration round for estimating the parameters.

6. CONCLUSION

Because the current analytical plotters are equipped with limited computer capacity, there is not yet a use for rigorous recursive block adjustment methods in practice. The software developed at Helsinki University of Technology is made to meet practical needs. It is naturally more complicated for the operator than the old systems, where he just observed the total block without having to think of anything else. On the other hand it brings new attitudes to the operator's work making it more challenging and interesting.

There are three subjects which have especially been under consideration when implementing the system. The main criterion has been operationality. It has been realized with menu techniques, help functions, and trying to install into the system specific operational features. Secondly, to control the quality of the measurements Baarda's reliability numbers are computed and gross errors are detected by computing the proper test criteria. The third aspect especially considered is automation.

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