A MULTIPURPOSE SYSTEM FOR THE PROCESSING OF GEOMETRIC OBSERVATIONS ADAPTED TO DIFFERENT COMPUTER INSTALLATIONS

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ABSTRACT

A powerful and flexible data processing system is a precondition of the versatile utilization of the potential of aerial and close-range photogrammetry. In the article there is described a computation procedure in which both iterative solution and direct solution are possible alternatives. Normal geodetic observations, photogrammetric observations, object coordinate observations, orientation observations and some calibration parameter observations can be used in the equations. The system has been programmed for different computers. Because of the flexible structure of the system minicomputers can be used or on the other hand, also the special capabilities of more effective computers can be exploited. At Tampere University of Technology the system is runnig in PDP 11/70, VAX 11/780 and in an attached arithmetic processor FPS-164.

INTRODUCTION

Simultaneous adjustment of different kinds of observations is in itself by no means new. For example, angle and distance measurements have been traditionally used in the geodetic determination of a control network. In network adjustment both observation types yield their own equations and appropriate weighting must be introduced for them. Unknowns are the planimetric coordinates and the orientations of sets of horizontal direction observations.

In the determination of photogrammetric coordinates, observations are represented by image or model coordinates. Unknowns are the object coordinates and the orientation parameters of the images or models. Photogrammetric coordinates are most often determined threedimensionally.

In geodetic point determination, sometimes for special reasons such items as the scale of the measured distances and the constant error are taken as unknowns. Such additional unknowns have also long been used in photogrammetric measurement in calibration tasks, and later also in so-called self-calibrating block triangulation. The obtained results have been good, especially in such cases where obligatory advance elimination of systematic errors is for any reason inexact (e.g. high altitude photography, camera malfunctions, etc.). Nevertheless, sufficient attention must be paid to the correlations and significance of these additional parameters.

Photogrammetric densification has characteristics of the following kind:

- x and y control points must be evenly distributed along block perimeters
- height control points must be evenly distributed over the whole area
- with the above preconditions, the standard deviation of the x and y coordinates of points to be determined is almost constant and depends primarily on the photoscale; the interpoint distance error is only weakly dependent on the point pair in question
- height accuracy is strongly dependent not only on the scale but also on the distance between height control points.

In cadastral surveying, interpoint-distance accuracy for adjacent points is a critical factor. Photography must be carried out at a low altitude, or else interdistances must be measured on the ground. The first applications of combined adjustment are from this problem area. To provide additional observations for photogrammetric block adjustment, distances less than a certain critical interpoint distance are measured on the ground.

In small-scale applications of aerial photogrammetry, height accuracy is often critical. Improvements have been made here by using additional observations. Some examples of these are APR observations, statoscope observations, and the heights of shore-line points. When there are insufficient height control points, the use of such additional observations can considerably improve the height accuracy of an aerial photogrammetric block.

The planimetric accuracy of an aerial photogrammetric block can naturally be enhanced also by using extra observations. It is probable, however, that the substituting of various distance and angle observations, etc. for control coordinates will remain slight. Observations must be so dense that they form an almost solid network, thereby reducing the cost effectiveness of the operation. However, the whole system can be processed more exactly which is surely a point of considerable significance.

Positioning systems are undergoing strong development. Observations can be made either from ground coordinates or camera stations. In both cases proper processing of observations requires a sufficiently versatile adjustment program.

In non-topographic applications of analytical photogrammetry the measurement of control data presents a central problem. Sufficiently accurate measurement of the control point coordinates is often almost impossible. On the other hand, distances, height differences, etc. are often relatively easy to measure, or else it is possible to use e.g. measuring rods. In addition, in non-topographic applications it is often easy to measure the photo orientation parameters, such as the distances between different camera stations, the directional lines of camera shots, etc. Effective and proper processing of such observations requires a versatile combined adjustment program which allows self-calibrating adjustment.

GENERAL CHARACTERISTICS OF PROGRAM

In 1977 the first combined adjustment program /1/ was produced as the result of team work between Tampere University of Technology, Helsinki University of Technology, and the Technical Research Centre of Finland. The program followed the same lines as the photogrammetric block adjustment programs developed earlier. The program has since then been further developed in Tampere University of Technology. In its present form the program is of the following type.

In addition to conventional photogrammetric observations (image and model coordinates), horizontal angle observations, vertical angle observations, slope distances, and height differences can be processed. Observations may be between object points, between projection centres, or between object points and projection centres. Object point and projection centre coordinates can be processed as fixed or free unknowns, or as observations. The same holds for the orientation angles. The self-calibrating parameters of the image coordinates also can be handled as free unknowns or weighted observations. Due to the structure of the program it is quite simple to add new types of observation equations to it. Up till now there has been no need for any other kinds of observations.

The structure of the program will be given more detailed treatment later. Let it suffice here to point out the dual nature of the solution part. In carrying out tasks of an extensive nature (thousands of unknowns), an iterative solution using the conjugate gradient method must be employed. In special photogrammetric tasks (or generally when the number of unknowns is of the order of hundreds) the direct elimination method can be employed, and it permits exact error control.

OUTLINE OF PROGRAM SYSTEM

Program operation follows the following principles (Fig. 1).

The first stage is to read all observations into the work file. Each observation group (image coordinates, model coordinates, horizontal angles, etc.) are fed in in the order in which they were observed. They may be given individual weight, or a common weight can be attached to the whole observation group. Approximative values must be given to the orientation angles and coordinates of images and models, but in general quite roughly estimated approximative values suffice. Likewise, approximative values are required for the orientations of sets of angle observations, but the approximative values of the object point coordinates can be left to the program to compute.

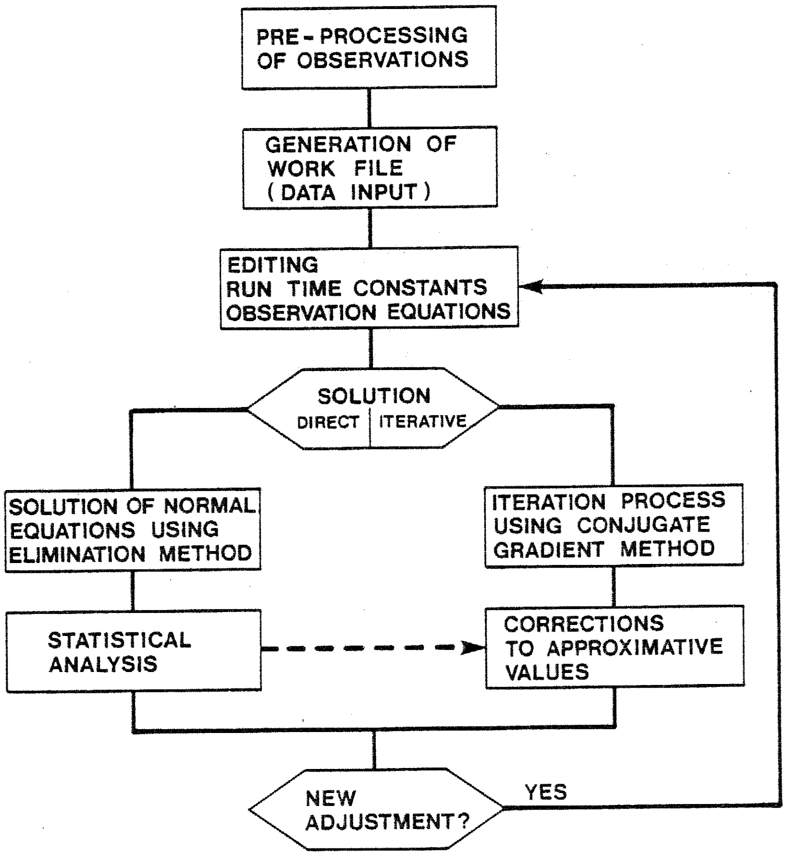

Fig. 1 Flow chart of program system.

Inputting observations forms the first stage of the program; data may be edited, if need be, in a second stage. In addition, observation equations are formed for the disc file. During editing, orientations and object coordinates can e.g. be altered, deleted or added to. One can also redefine which coordinates or orientations will be handled as fixed, free unknowns, or as observations. Furthermore, the selection of additional parameters is made. Any combination whatsoever of 12 parameters can be selected for computation.

The observation equations $A\ x + l = v$ are produced in collapsed form for the program work file (Fig. 2). This means that the zero elements of the coefficient matrix are not recorded. In addition to the non-zero elements themselves, data concerning the address of the elements in question must be recorded. In the present program this has been effected by supplying information at the beginning of each equation on the number of non-zero elements and the sequence numbers of the unknowns which they concern. At the same time other data also are recorded, such as weight and observation. These are exploited at the stage where the equations are regenerated during the iteration process.

Note that operations of the type A^TA and A^Tl can be carried out as one sequential access of file A.

n	i_1	i_2	......	i_n	a_1	a_2	... ...	a_n	......	W	parameter data	l

n	number of coefficients
$i_{1...n}$	sequence number of unknowns
$a_{1...n}$	coefficients of unknowns
W	weight

Fig. 2 Principle of collapsing an equation. The figure does not exactly correspond to the actual program.

There exist completely divergent solution alternatives. Employing the iteration process using the conjugate gradient method, even a small computer gives large capacity in reasonable time. The solution can be effected also by the direct elimination method, which permits thorough error and accuracy control.

In general use are optimized methods which attempt to form a banded bordered normal equation matrix. Especially in non-topographic applications it is necessary to employ very diversified observations, which leads to a normal equation matrix becoming comparatively filled (Fig. 3). Because there was no desire whatsoever to limit the system, the direct elimination method has been employed. This has been implemented both on the VAX 11/780 system and on the attached FPS-164 arithmetic processor. Aspects of the hardware are treated in more detail in the next section.

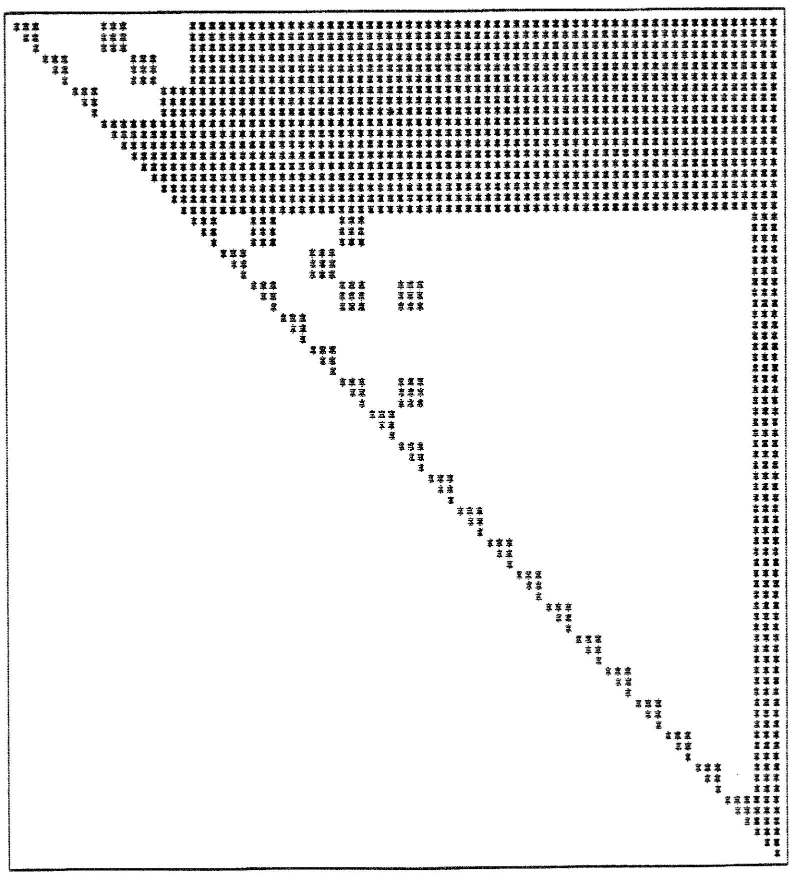

Fig. 3 Typical normal equation matrix in non-topographic measurement.

Corrections of the approximative values of unknowns are added after the solution, and new equations based on the corrected approximative values are formed. This iterative calculation is carried out with the conjugate gradient method. There is usually only need for the inversing of normal equation matrix once only in connection with error control.

CALCULATION ALGORITHMS AND COMPUTERS

The coming into general use of minicomputers since the beginning of the 1970's and their continuous development has been a factor of quite general significance in the development of programs /2/. The amount of main memory of minicomputers was originally quite small. For example the first stage of this combined adjustment program was prepared in 1977 for the HP2100 computer in the Institute of Photogrammetry of Helsinki University of Technology, which had only 16 kilowords (each of 16 bits) of main memory. The system relied completely on disc memory. With the software it was possible to solve tasks with thousands of unknowns. At the same time the program was in the PDP 11/70 computer at Tampere University of Technology. Since this computer had dozens of simultaneous users, the system relying heavily on a disc file was very slow. When the university acquired a VAX 11/780 computer, the program was converted to this hardware in 1981. The solution was then transferred to the main memory (virtual memory). The time spent on a solution thereby decreased substantially.

In topographic applications block structure (point distribution and overlap relations) follows certain standard cases. Quite many theoretical and empirical accuracy investigations have been carried out. In practical aerial triangulation work, problems are often due to the fact that compromises have been made on the basic requiremets of block structure on account of lack of expertise or some other reason. The consequences are often unpredictable and the situation cannot be essentially remedied by calculation methods.

Non-topographic applications have become quite widespread. Naturally there exist their own standard methods for such tasks also, and their characteristics have been the subject of much research. However, compared with aerial photogrammetric applications, the tasks are very varied and questions of accuracy, etc. must be analysed individually. For example the substitution of geodetic observations for control coordinates is a matter whose effects even an experienced photogrammetrist cannot estimate without exhaustive error analysis. Reliable handling of non-topographic applications therefore presupposes the inversing of the normal equation matrix, at least in its essential parts. In this program the inversing is performed in its entirety. This can be performed either on the VAX 11/780 or since the beginning of 1984 on the attached processor FPS-164.

The attached processor FPS-164 has been designed for the processing of major scientific and engineering applications. It operates as an attached arithmetic processor to the host computer. The host computer in Tampere University of Technology is the VAX 11/780. The FPS-164 provides fast 64-bit computation and a large memory. It is programmed using an optimizing Fortran-77 compiler. Fortran-callable subroutines give increased performance.

On average the FPS-164 is about ten times more efficient in arithmetical calculations than the VAX 11/780, but in some cases the difference can be considerably greater. When there are several dozens of simultaneous users for the VAX, the FPS is entirely reserved for one user. For this reason program performance time (total time) when using the attached processor is quite substantially shorter than on the VAX computer.

SUMMARY AND ADDITIONAL REMARKS

The program described above is used for both aerial and close-range photogrammetric applications. In large-scale cadastral surveys mainly interpoint distances (e.g. boundary lines), and sometimes also horizontal angles (e.g. three points in the same vertical plane) are entailed. In special applications, on the other hand, often even all observation types are involved. In such cases the geodetic observations are between the object points, between the projection centres, or between object points and projection centres. Reliable performance of this type of task presupposes thorough individual error analysis. In connection with this program a complete variance-covariance matrix can be employed. The structure of the measurements can be tested in advance and the required changes made. Unfortunately, this solution based on direct elimination succeeds in practice only when dealing with a few hundred unknowns. For example, when using the FPS-164 arithmetic processor, the inversing of a 300 x 300 element matrix takes about half a minute. No close-range photogrammetric task greater than this has generally arisen. However, the number of unknowns in aerial photogrammetric applications is often considerably larger. In such cases it is necessary in practice to employ the conjugate gradient method. This is in itself an especially fast and effective means of solving a large equation group. Iteration in normal photogrammetric blocks is fast. The drawback, however, is the poor possibility of effective error analysis.

The program outlined above is in regular use for both practical applications and research work. Many other effective principles (e.g. /3/) can be followed in the adjustment. The present system has shown itself very flexible and versatile, which in the case of universities is very important.

REFERENCES

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