14th Congress of the International Society for Photogrammetry
Hamburg 1980
Commission III
Presented Paper

K. Jacobsen, M. Worzyk

Institut für Photogrammetrie und Ingenieurvermessungen, Universität Hannover
Federal Republik of Germany

Experiences with Bundle Block Adjustments on Mini-Computers

Abstract

The Hannover Bundle Block Program System was adjusted für the Mini-Computer HP 1000 (HP 21 MX). The installation of such an extensive program system on a mini-computer produces special problems. Of advantage is the possibility of a dialogue during the assembly of the input data.

Kurzfassung

Das Hannoversche Bündelblockprogrammsystem wurde für den Mini-Computer HP 1000 (HP 21 MX) umgeschrieben. Die Installation eines derart umfangreichen Programmsystems auf einem Minicomputer ergibt besondere Probleme. Vorteilhaft wirkt sich die Möglichkeit eines Dialogbetriebes auf die Bereitstellung der Eingabewerte aus.

1. Configutation of the Program System

The practice-tested Hannover Bundle Block Adjustment Program is, for work-organizational reasons, divided into two independent programs. The preprocessing program computes the image coordinates, sorts them into the sequence required for the adjustment, and carries out the first search for errors. The main program is limited to the adjustment. In the program version for the HP 1000, the main program had to be further sub-divided into (a) the dialogue program for the input of job control data and (b) the actual adjustment program. This concept formed the basis for the Version 1 of the bundle block program for HP 1000, which was ready in 1979.

The preprocessing program BLAPP (bundle adjustment preprocessing program), consists of a dialogue part, in which the program demands some job control data and error limits, and a computational part. It normally accepts image coordinates measured on the Zeiss Planicomp and stored on magnetic disc. If the measurements are done on the Mono-comparator Zeiss PK 1, then these measurements must be rearranged into the format of the Planicomp data using an auxiliary program. The preprocessing program BLAPP makes no high demands on the computer and may, without problems, be run as back-ground program. In Version 1 of the bundle block program for HP 1000, the necessary data are transfered by means of a magnetic cartridge from the program BLAPP to the dialogue program for input, BLIM (bundle adjustment input for main program). The dialogue program BLIM takes all necessary block adjustment data, and makes only very little demand on the computer. In Version 1, the job control data are transfered by means of a magnetic cartridge from BLIM to the Bundle Block Adjustment Program BLUH (bundle block adjustment

University Hannover).
Computation in the adjustment program BLUH is intensive, the job time depends a lot on the other demands on the computer. It can however also run unsupervised, for example at night. The computed point coordinates and the photo orientation elements can be stored on magnetic disc (General File) and are ready for further processing. In case there are still errors in the aerial-triangulation block, the computed photo orientation elements from a previous adjustment could be considered as refined data and applied to a second block adjustment to cut down on the computation time. Data errors may not be corrected in the original input data set, but rather in an error correction list of the program BLAPP or BLIM.
This program set-up has been proved efficient in practice. Since errors are inevitable in larger aerialtriangulation blocks, the adjustment should normally be computed several times with progressive error correction. As far as error correction for the program BLUH is concerned, it is often enough just to rerun the program BLIM or BLAPP.
However, data tranfer by means of magnetic cartridge is not efficient. Magnetic cartridges are slow, and very susceptible to disturbance at higher transfer rates (baude-rates). On the other hand, work with magnetic cassettes do not strain the magnetic discs, although this situation is observable for small discs and intensive use. The long engagement of the printer by the program BLUH has groved to be an additional disadvantage. For these, and other, reasons (see article 2) a fundamental revision of the program system to Version 2, had become a necessity, and hence the implementation of data transfer by means of File (magnetic disc) from BLAPP to BLIM and from BLIM to BLUH. Now, work can be done alternatively with magnetic cartridge or File. Moreover, data for printing can either be given directly to the printer or stored on File. The auxiliary program for output-printing, BLOM (bundle adjustment output of main program), then reads this File and produces an output list with no time interruption. The adjustment program BLUH no longer blocks the printer, and during unsupervised operation, there are no problems with the functioningof the printer.

2. Engaging the Computer Core and Computation Time

The Computer HP 1000 is as a rule used with a core storage of 128 K, 16 bit-words. This core could just take the whole bundle block adjustment program, and therefore offers no space for the data. For this reason, the program had to be segmented. Even after the segmentation, there is very little space left for the data, so that for parctical application, the capacity would have been insufficient if magnetic discs as temporary storage were not extensively used and if the advantages of the diagonal structure of the normal equation matrix were not exusted.
Block adjustment is a non-linear adjustment problem, which produces rigorous results if the approximate values are updated in several iterations. Usually, more than 5 to 6 iterations are not necessary. After the second iteration, the approximate coordinates are, from experience, so good that the normal equation coefficients do not change any more. This fact is put to an advantage by the program BLUH which computes the normal equation system only during the first three iterations. The coefficients are therefore put on File for use in the fourth and further iterations, where the computation time is cut down by about 1/3. On the whole, 6 different Files are required for temporary storage of data. In this way, by the good use of the available core space, the Bundle Block Adjustment System BLUH, offers about 75 % of the capacity to compute a maximum of 300 photographs and 1800 object points at a maximum of 9 photos per point.

The number of additional parameters for accuracy improvement is limited to 4, which, from experience, remove most of the systematic image errors, and which also, under unfavourable conditions, do not hide the danger of the worsening of the results.

The computation times of the first three iterations may beestemated by the following formula:

$$t\ [sec] = F \cdot PL \cdot PC^2 \cdot \frac{PP}{14}$$

t = computation time for one iteration

PL = photos in the longitudinal direction

PC = photos in the lateral direction

PP = average number of photo points per photo

F = factor for computation time

Version 1 showed a striking irregular relationship between the execution time (CPU-time) and the idle time (job-time) in the computer. The factor F for the idle time had the value 30, corresponding to about 12 minutes for a block of 2 strips with a total of 11 photographs. For the execution time, F was below 1. These uncomfortable relationships could be explained by the fact that, with one exception, the same buffer was employed for all Files. In other words, almost every reading of disc data meant a direct reading of the disc. In Version 2, for this reason, every File got its own buffer, and hence, the idle time of the program got considerably reduced.
Under favourable conditions, with all data on the same disc, a factor for the idle time of F = 1.5 could be attained for an HP 1000 with E-processor and hardware Extended Memory, which could correspond to an idle time of 33 secondsfor the block of 11 photographs for an iteration.

In the most unfavourable case, where the data were distributed to different discs and moreover a slower disc unit and on E-processor with software Extended Memory were involved, the factor was 4 to 5, corresponding to 90 to 120 seconds. With today's computer with F-processor, computations can be done twice faster, in which case F would then be reduces to under 1.0.
For large amounts of data, the preprocessing program BLAPP carries out the very extensive sorting of the measurements. By using modern sort-and search algorithms (see article 4), the time required could be reduces to a trifle.

3. Experiences with Actual Block Adjustments

With the program system BLUH, blocks measured mainly on the Planicomp have been adjusted on the HP 1000. In comparison with comparator measurements, the computer supported measurements have drastically reduced the number of identification, and numbering errors in the respective strips, so that the only errors to expect were those due to the quality of the control points and also due to the numbering of points existing in more than one strip. The different points that have received the same number have already partly been singled out by BLAPP. The remaining blunders could easily be found out by error messages built-in in the program BLUH.
Some aerial-triangulation blocks were even error-free, which is a situation that is very seldom for comparator measurements.

The input of the job control data in dialogue has very much simplified work with the program system. After a very short introduction, persons who had never run a block adjustment, could independently run the computations.

The bundle block adjustment program BLUH for the HP 1000 contains only 4 additional parameters for the elimination of systematic image errors, whereas the Hannover Bundle Block Adjustment Program for the large computer contains 24 different additional parameters, whose influences could be limited to block sections, so that in a large block, the computation could be done with several combinations of the 24 additioned parameters. It has been proven in practice that it is only in a few cases that this highly developed method may be applied for the minute aspects of image geometry. The obtainable accuracies in a bundle block adjustment with 4 additional parameters (which eliminate most of the systematic image errors) are, as a rule, limited by the accuracy of the control points used. Moreover, experience has shown that, in spite of the statistical tests, built-in in the program for the large computer, users, who are not very familiar with the theory of block adjustment, may make the wrong choice of additional parameters, which would not improve, but would rather, worsen the results (see Jacobsen /2/).

The deliverate waiver of a very complicated method of eliminating the last traces of image geometry errors has, in practice, been proved to be advisable. An accuracy increase of more than 10 % for aerial triangulation blocks with Planicomp measurements of up to 300 photographs, is hardly expected, not even under favourable conditions.

4. The Sort-and Search Algorithms used

As already mentioned, the measured image coordinates are so sorted by the program BLAPP that they are in the optimal arrangement for block adjustment by BLUH. It is only when the diagonal structure of the normal equation matrix is taken full advantage of that a block adjustment with up to 300 photographs and up to 7200 unknowns on a mini-computer is possible.

Following is a description of the Algorithms with the aid of which this sorting is carried out. Considered as the scale for measuring the speed of an algorithm, is the number of comparisons that a computer must carry out until a definite element is found or is located in its place.

First of all, the sizes of the elements of the photo number list are sorted with the aid of the "Natural two-way Merge Sort" Algorithm [3]. For the sorting, this algorith requires, for n elements, 2 n storage places and less than 3 n [1 + lb (n)] comparisons (lb = logarithm binary = exponent of base 2). The procedure is explained in the following example: A given series of numbers (Figure 1, first row) is broken up into sub-series each in ascending order, starting simultaneously from both ends of the row, as indicated by the arrows. Starting from both ends, the two sub-series are combined in an ascending order into a sub-series and once again written onto an auxilliary row from both ends inwards (Figure 1, second row). This procedure is repeated as many times as necessary to get the Elements arranged (maximum [1 + lb (n)] times).

It is relatively easy to find an element in a sorted set: The middle element is compared with the one required. If it is smaller, then the middle element of the upper half is taken. If ist is larger, then the middle element of the lower half is taken, and so on. This algorithm is

Figure 1

2 8 6 28 30 13 12 17 22 10 1 25 19 20 16 3

2 3 8 16 20 1 10 13 22 17 12 30 28 25 19 6

2 3 6 8 16 19 20 25 28 30 22 17 13 12 10 1

1 2 3 6 8 10 12 13 16 17 19 20 22 25 28 30

called "Logarithmic searching" (Wegner /6/). Figure 2 shows the sequence of the elements which are compared if the element 16 in the 4th row of figure 1 is being sought for.

Figure 2

13 20 17 16

With the aid of this algorith, it could be known with a maximum of $2\,[1 + \mathrm{lb}\,(n)]$ comparisons, whether an element among n given elements exists, and at which location.

With these algorithms in the program BLAPP, a maximum of $7 \cdot n \cdot [1 + \mathrm{lb}\,(n)]$ comparisons are required for the sorting. (n = No. of photographs in the block). If on the other hand, the corresponding elements were always searched for from the beginning of the list, then a maximum of $2 \cdot n \cdot (n + 1)$ comparisons would be necessary. In practice, this means a shortening of the computation time to 32 % for 64 photographs in the block, and to 10 % for 250 photographs.

References

/1/ H. Bauer, J. Müller: Height accuracy of blocks and bundle adjustment with additional parameters. ISP Ottawa, 1972

/2/ K. Jacobsen: Attempt at obtaining best possible accuracy in bundle block adjustment. ISP Hamburg 1980, Com. III, WG 3

/3/ K. Jacobsen: Bundle block adjustment with small format photographs, ISP Hamburg 1980, Com III, WG 3

/4/ J. Müller: Blocktriangulation mit Verbesserung der inneren Orientierung. Bildmessung und Luftbildwesen 1971 S. 10

/5/ D. E. Knuth: The art of computer programming. Reading, MASS.1973

/6/ P. Wegner: Programming languages, information structures and machine organisation. London 1971

Appendix 1

Program Configuration, Datastream