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AEROTRIANGULATION WITH PLANICOMP C-100 AND THE STUTTGART PROGRAMS

H. Klein, Stuttgart

The aerotriangulation was influenced by the development of electronic computers more effectively than perhaps all other conventional subjects of photogrammetry. In the beginning of aerotriangulation the photogrammetrists looked for analogue solutions. Complicated numerical calculations were avoided. The development of larger and more powerful computers lead via polynomial methods to the present methods of independent models and of bundle adjustment. In order to reduce the amount of control points and to correct systematic errors within the adjustment, auxiliary data and additional parameters may be included. The present techniques are distinguished by the possibility to adjust blocks of models or bundles with any overlap. It is essential that a rigorous adjustment is performed, with respect to all connections and control points, and that all models or bundles are transformed and the coordinates of all points determined simultaneously.

Theoretical investigations have shown and practical adjustments have verified an enormous reduction of control points by block adjustment with the present methods, in particular in case of large blocks. The absolute accuracy of block adjustments is essentially dependent on the accuracy of measured image- or model coordinates. Therefore, on the one hand large blocks for small scale mapping are economic and practical, and on the other hand high precision photogrammetry is possible for cadastral surveys and other point determination.

The relationship between absolute accuracy, measuring accuracy, control point distribution, and the other project parameters are sufficiently well known for project planning. Thus the block adjustment is unproblematic, in a way, apart from the dependence on powerful computers and adequate programs. At the Institute of Photogrammetry of Stuttgart University we therefore took up the task to make this new standard of efficiency and accuracy of aerotriangulation accessible and workable for practical application. Since 1968 we have developed general purpose programs for block adjustment by the method of independent models and by bundles. Regarding the complexity of problems to be solved and in order to avoid any initial limitations, we relied on large computer systems. The computer programs are written in Fortran IV language. They are transferable to all computers of suitable capacity.

As it seemed more useful for practice, we started with the block-adjustment program PAT-M 43 for independent models.
The three-dimensional similarity transformation iterating between planimetry and height is performed by a straight forward least squares solution. The problem is non-linear, therefore the adjustment has to be iterated. APR-profiles and statoscope measurements or height information from shorelines of lakes can be used besides the measured model coordinates and the coordinates of control points. In addition to the generality of the method I like to point out two characteristic features of the program:

1. Within an extremely wide range, the program is practically not limited as to block size, multiple overlap, or the number of points. Thus the program does not impose any restrictions for the planning of a photogrammetric project. Multiple photo coverage and cross strips, additional statoscope measurements, everything considered necessary to get a certain accuracy can be handled by the program. If necessary or expedient for any reason, blocks with a thousand and more models or blocks with several hundreds of points per model can be adjusted.

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2. The program is extremely easy to handle. There are, besides one exception (points of shorelines of lakes), no coding specifications. The type and the multiplicity of points are recognized and coded by the program through equal point numbers. The read in data are sorted in an optimum sequence for efficient computing time. All data are checked for recognizable errors.

This concept of a program with rather rigorous adjustment, with no restrictions and limitations in practice, and with a comfortable handling, implies an extremely large number of arithmetical operations: linear equation systems of up to ten thousand unknowns have to be solved. Special problems arise from the amount of data to be controlled, processed and stored.

The following examples show the quantities of data to be processed with block adjustment. It is especially data storage which presents serious problems.

Data storage for block adjustment

	1st example	2nd example	3rd example
models	300	1 000	100
strips	10	20	5
models per strip	30	50	20
points per model	10	10	300
coefficients for partially reduced normal equations (planimetry)	60 000	350 000	12 000
storage space for photogrammetric measurements	15 000	50 000	150 000
total storage required,			
- in double precision words	75 000	400 000	162 000
- in K-bytes (IBM)	600	3 200	1 296
- in K-16 bit words (Hewlett Packard)	225	1 200	486

Such quantities of data are too large for being stored directly in the central memory of a computer. They have to be stored externally on a high-speed storage unit with direct access, from which they are transferred to be central memory whenever needed for further processing. During execution those data will be required not only once but at least 50 - 100 times. Even very fast discs have an average access time of 30 milli-seconds. Therefore the data cannot be transferred individually from disc to the main storage and vice versa as even small photogrammetric blocks would then need several hours of computation time. It is necessary to combine the data in packages, the so-called records, which then can be treated as a unit. In the main storage capacity for a few records only is required.

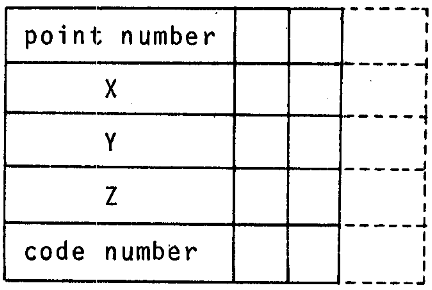
Any program with extended data transfer from external to central storage has to be optimized with respect to the records. The collection of data in records has to be done in such a way that exactly those data, which are required at a certain time are combined in the same record. The program flow has to be optimized with respect to the number of record transfers. Therefore each algorithm has to be conceived individually.

In the program PAT-M 43 we have several different types of records:

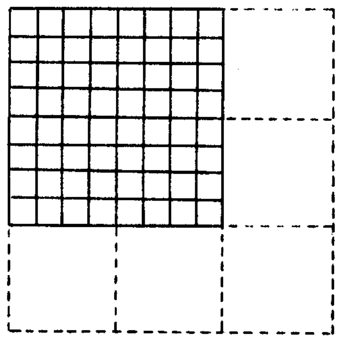
1. point records for the photogrammetric measurements and for the control points: Point number, 3 coordinates and an internal code number are stored.
2. model records to store model numbers, the number of measurements in the model, an address code for the measurements and the model connections.
3. records for submatrices of the reduced normal equation system which result from subdivision by a symmetric grid.

Records for data transfer with PAT-M 43

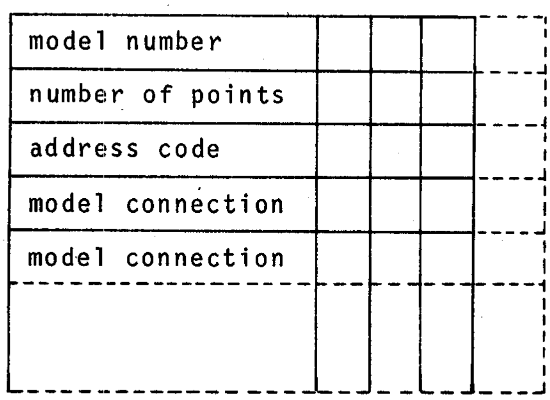
point records



submatrices (planimetry)



model records



In order to have an optimal flow of computation, we need storage space in the main storage for two point records of the photogrammetric measurements, one point record for control points, two model records, and three records for submatrices of the reduced normal equation system. Two records for submatrices can have the same storage allocation as the point- and model records because they are not used at the same time. Hence again the required storage capacity is reduced. The size of the records can be declared arbitrarily during the implementation at a certain computer. There are, however, some restrictions like: the pointrecords must be big enough to include all measurements of a single model or all vertical or horizontal control points.

Up to now the program has been implemented at 38 computers. The following table shows comparable computing times for block triangulation with PAT-M 43 for various types of computers.

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Computing time (CPU) for block adjustment with PAT-M 43

received by adjustment of the same regular square shaped block of 72 models in 6 strips, with 1341 photogrammetric points (19 measurements / model) and 3 plan-height iterations:

computer	CPU-time in seconds/model
CDC CYBER 74	0.52
CDC 6600	0.58
UNIVAC 1110	0.91
IBM 360/85	0.95
CDC CYBER 174	1.05
IBM 370/165	1.08
UNIVAC 1108	1.36
UNIVAC 1106	2.8
IBM 370/158	3.1
IBM 360/75	3.2
CDC 6400	3.2
IBM 370/155	3.4
HONEYWELL BULL 6060	4.8
IBM 360/65	5.0
IBM 370/145	5.6
DIGITAL EQUIPMENT DEC 10	15
IBM 360/50	21
PDP 11/45	35

The computing time is proportional to the number of models up to blocks of several hundreds of models, beyond which it is slightly increasing. By doubling the photogrammetric measurements within the same number of models the computing time is increased by 15 %.

In the past we have often been asked to develop block adjustment programs suitable for minicomputers. However, we have hesitated for a long time, because of the following considerations:

1. Simplified programs for block adjustment would push a considerable amount of effort like coding and sorting of data into the preparation of the project. The result is inefficiency, at the least, or it may be totally prohibitive.
2. Simplified methods for block triangulation and the limitations implied result in wasting accuracy, in severe restrictions, and they prevent the capability and efficiency of aerotriangulation to be fully utilized.

Recently, however, the capability of minicomputers has been advanced to a point that block-programs seem possible without serious loss of generality.

During the ISP congress in Helsinki 1976 the Carl Zeiss company has introduced the analytical system PLANICOMP C-100. Part of this system is the minicomputer HP 21 MX of Hewlett Packard with a main storage of 32 K 16-bit words which is used as process control computer. With a cycle time of 625 nanoseconds it is fast enough to execute programs in time-sharing besides measuring with the Planicomp. However, in time-sharing only 16 K 16-bit words are available for computation. With the additional expense of 14.000 DM the main storage can be increased to 64 K. Programs then could make use of 32 K. Larger space is not possible for a Fortran program due to the limited address part of an instruction. The development of the minicomputers to reasonably cheap but powerful systems induced us to reflect on how the implementation of the PAT-M 43 program to this kind of computers could be done. Our main objective was to succeed in implementing the program without serious restrictions.

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The program PAT-M 43 consists of a main program and 90 subroutines with approximately 6500 instructions. The instruction part alone (without working area) needs 250 K-bytes storage allocation on an IBM computer. This is equivalent to 125 K 16-bit words on the Hewlett Packard HP 21 MX minicomputer. Even for very large computers the requested storage is still too big or leads alternatively to great costs or to not acceptable waiting times. There are two possibilities to solve this problem:

1. Partitioning of the program into separate and successively processed subprograms. The data transfer from one program to the next is done by using intermediate external storage. The first version of the program of 1971 contained partitioning into 4 parts of 100 K-bytes each. Further partitioning into separate programs is hardly reasonable because of the increasing job control problems, also in view of the non-linear adjustment which has to be iterated.
2. In principle the storage allocation for the program instructions must be optimized in the same way as we did already with the working area for data processing by using records. This technique of using repeatedly internal storage for the instruction part during different stages of program execution is called overlay or segmentation.

Of course, during the program execution, not all of the 90 subroutines are called upon at the same time. When one routine is no longer needed in storage another routine can replace all or part of it. Only the main program and some routines remain permanent in internal storage. Most of the computer systems have such possibility to use segmentation directives for controlling the subsequent loading of program parts during execution.

Thereby it was possible to reduce the necessary internal storage for the instruction part of PAT-M 43 to 100 K-bytes or 50 K 16-bit words, respectively. However, this storage requirement is still too big for the HP 21 MX. Therefore the program was optimized once more with regard to overlay of subroutines. Bigger subroutines have been cut into smaller pieces. Program parts executed differently at different times have been divided into instruction sequences not needed to remain in internal core simultaneously.

After such changes the present program consists of 118 subroutines (previously 90) and of 8100 instructions (6500). Now segmentation with 25 segments in one level is possible. As a result of such extreme segmentation only 11.5 K 16-bit words of internal storage are needed for the instruction part of the program on the HP 21 MX. Thereby 4.5 K respectively 20.5 K with extended memory remain which are available for the different data-records. Hence, the following program versions of PAT-M 43 can be implemented on the HP 21 MX:

Storage allocation of PAT-M 43 on the HP 21 MX

	normal version	extended memory version
INSTRUCTION PART	11 500 16-bit words	11 500 16-bit words
1. POINT RECORD	300 DP words	1 400 DP words
2. POINT RECORD	300 DP words	1 400 DP words
CONTROL POINT RECORD	300 DP words	1 400 DP words
1. MODEL RECORD	100 DP words	500 DP words
2. MODEL RECORD	100 DP words	500 DP words
SUBMATRICES	288 DP words	1 308 DP words
STORAGE INSTRUCTIONS	11 500 16-bit words	11 500 16-bit words
STORAGE RECORDS	1 388 DP words	6 508 DP words
STORAGE TOTAL	15 664 16-bit words = 15.7 K 16-bit words	31 024 16-bit words = 31.1 K 16-bit words

Because of the limitation of internal storage for the records we have the following restrictions:

Restrictions of PAT-M 43 on HP 21 MX

	normal version	extended memory version
PHOTOGRAMMETRIC MEASUREMENTS / MODEL	60	280
CONTROL POINTS / LIST resp. APR- or STATOSCOPE POINTS	60	280
MODELS IN ONE GROUP	19	49
NUMBER OF MODELS	320	720

Adjusting a photogrammetric block of 10 strips with 30 models each, altogether 492 times parts of the program will be repeatedly loaded. It seems to be much, but will amount to only 1 - 10 % of the total execution time.

Using the minicomputer version on large computer systems the working area can be extended by saving storage for the instruction part.
Therewith on a CDC 6600 the time for repeated loading has been more than compensated by saving time for data transfer with the external storage. The total execution time became faster than with the former version.

By omptimization of the working storage and the area of the instruction part and by use of a high-speed disc the implementation of the program PAT-M 43 became possible on minicomputer of the HP 21 MX type. With that a wide range of applications for aerotriangulation can be covered without essential restrictions.

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Abstract

The Institute of Photogrammetry of Stuttgart University has written two computer programs for aerotriangulation with the C-100 PLANICOMP/ Hewlett-Packard 21 MX system. The programs use the least-squares method to solve the task of aerotriangulation of independent models in strips and blocks. Orientation parameters and unknown coordinates are determined separately for horizontal and vertical position by simultaneous adjustment. The block program has been developed from the PAT-M 43 program with simultaneous adjustment of APR and statoscope measurements and Lake-information, which has been successfully used in practice for six years. The paper discusses the general character, the efficiency and the limits of the programs with regard to the Hewlett-Packard 21 MX minicomputer.

Zusammenfassung

Am Institut für Photogrammetrie der Universität Stuttgart wurden für das System PLANICOMP C-100/Hewlett Packard 21 MX zwei Computerprogramme für die Aerotriangulation entwickelt. Die Programme lösen die Aufgabe der Aerotriangulation von unabhängigen Modellen im Streifen- und im Blockverband nach der Methode der kleinsten Quadrate. Die Orientierungsparameter und die unbekannten Koordinaten werden getrennt nach Lage und Höhe in einer simultanen Ausgleichung bestimmt. Das Blockprogramm ist eine Weiterentwicklung des seit 6 Jahren in der Praxis bewährten Programms PAT-M 43 mit simultaner Ausgleichung von APR- und Statoskopmessungen und Lake-Information. Die Allgemeinheit, Leistungsfähigkeit und die Beschränkungen der Programme in Bezug auf den Kleinrechner Hewlett Packard 21 MX werden vorgestellt.

Résumé

L'Institut de Photogrammétrie de l'Université de Stuttgart a élaboré pour le système PLANICOMP C-100 deux programmes de calcul destinés aux triangulations aériennes. Ces programmes servent à la triangulation aérienne sur modèles indépendants par bandes ou blocs de bandes, d'après la méthode des moindres carrés. La détermination des paramètres d'orientation et des coordonnées inconnues s'opère séparément pour la planimétrie et l'altimétrie, avec une compensation simultanée. Le programme pour l'aérotriangulation sur blocs de bandes est dérivé du programme PAT-M 43 qui est mis en oeuvre depuis six ans pour les données fournies par les altimètres-radars et les statoscopes, avec compensation simultanée et information Lake. L'exposé examine l'universalité, la rentabilité et les restrictions des programmes en relation avec le petit calculateur Hewlett Packard 21 MX.

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Resumen

El Instituto de Fotogrametría de la Universidad de Stuttgart ha desarrollado dos programas para triangulación aérea mediante el sistema PLANICOMP C 100/Hewlett Packard 21 MX. Los programas resuelven la tarea de la triangulación aérea de modelos independientes en fajas y bloques según el método de los mínimos cuadrados. Los parámetros de orientación y las coordenadas desconocidas se determinan separadamente por planimetría y altimetría en una compensación simultánea. El programa de bloque es una ampliación del programa PAT-M 43, empleado con mucho éxito en la práctica desde hace seis años, con compensación simultánea de mediciones APR y de estatóscopo, así como de información Lake. Se exponen la generalidad, el rendimiento y los límites de los programas con respecto a la minicomputadora Hewlett Packard 21 MX.

Dipl.-Math. Hermann Klein
Institut für Photogrammetrie der Universität Stuttgart
Keplerstr. 11, 7000 Stuttgart 1