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Realizing Automatic Aerotriangulation

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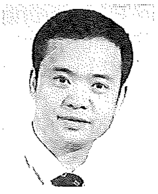

Realizing Automatic Aerotriangulation

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Abstract

Automation in digital photogrammetry of today brings much more economy in the practice than ever before and is now in the course to revolutionize again the daily production since the boom of analytical photogrammetry about three decades before. In this sense, automatic aerotriangulation proved to be very promising. The paper deals with thoughts and strategies for realizing a commercial system of automatic aerotriangulation. The idea of "block as a whole" leads to great success in autonomous processing. "Image connection" provides high robustness of the procedure and thus high reliability of achieved results. It has proven that automatic aerotriangulation meets the accuracy requirements of practice and is much more economic than conventional approach.

Zusammenfassung

Automation in der digitalen Photogrammetrie bringt heutzutage viel mehr Wirtschaft in der Praxis als zuvor und ist nun gerade auf dem Weg, die tägliche Produktion seit dem Boom der analytischen Photogrammetrie vor etwa drei Jahrzehnten nochmals zu revolutionieren. In diesem Sinne hat sich die automatische Aerotriangulation als sehr vielverprechend herausgestellt. Der vorliegende Beitrag befaßt sich mit Gedanken und Strategien zur Realisierung eines kommerziellen Systems der automatischen Aerotriangulation. Die Idee von „Block als ein Ganzes" führt zu großem Erfolg bei der autonomen Verarbeitung. „Bildverknüpfung" bietet hohe Robustheit des Verfahrens und insofern hohe Zuverlässigkeit der erzielten Ergebnisse. Es hat sich gezeigt, daß die automatische Aerotriangulation den Genauigkeitanforderungen der Praxis entspricht und zwar viel wirtschaftlicher ist als konventionelles Verfahren.

1. Introduction

The most significant feature of digital photogrammetry of today is the high automation of individual processing procedures, e.g. automated film scanning, automatic interior and relative orientation, automatic digital terrain or surface modelling, automatic orthoimage generation and automated image plotting [3, 15]. This brings much more economy to the photogrammetric practice than ever before and is now in the course to revolutionize again the daily production since the boom of analytical photogrammetry about three decades before.

Aerotriangulation (AT) is an essential task in photogrammetry. With introduction of computer technologies in photogrammetry in the sixties and seventies of this century, great technical jump had been achieved also for aerotriangulation [1]. Orientation parameters of images can be determined computationally by block adjustment programs and point measurement can be supported conveniently by analytical instruments. However, the tie point selection, transfer and image coordinate measurement in the course of analytical AT still require intensive interaction of a human operator and belong to the most laboured and time-consuming work. Thus, automation of these steps is highly desirable in practice.

Digital photogrammetry uses digital or digitized images as information carrier. Thus, numerical operations of images become possible and so does automation of photogrammetric processing procedures. With success in algorithmic development of digital image matching techniques and their application for e.g. relative orientation [17, 18], automation of AT has become a focus in research and development since early the nineties, e.g. [2, 6, 11, 13, 14, 19]. Commercial systems of automatic aerotriangulation are now available on the market, e.g. [4, 10, 12], and have already successfully been used in the daily production, e.g. [8, 9].

PHODIS AT is the commercial system of automatic aerotriangulation of Carl Zeiss company and has gained quite great success in photogrammetric practice already. To complement early publications [4, 14, 16], the paper focuses on strategic issues for realizing the system. The idea of "block as a whole", which leads to great success in autonomous processing, is presented. Principle of "image connection" is outlined. Results obtained by using data sets directly from practice demonstrate robustness, reliability and economy provided by the automatic aerotriangulation.

2. Analysis and Definition

Aerotriangulation (AT) determines exterior orientation parameters of images of a photogrammetric block by means of a block adjustment using tie points determined in the neighbouring images and some known ground control points (GCPs), which are well distributed over the block and also identified and measured in those corresponding images. An indoor analytical AT procedure can consist of four processing steps, i.e.

- Block preparation, where among others images are ordered according to flight plan, camera data and ground control information (e.g. GCPs) are collected.
- Tie point determination, which includes
  - point selection, where distinct image points are chosen around standard positions, marked and assigned with unique names or number codes;
  - point transfer, where selected image points are transferred to the neighbouring images by means of e.g. a point transfer device;
  - measurement of image coordinates of tie points, which can be performed in mono or stereo mode on a comparator or an analytical plotter.
- GCP acquisition in images, where GCPs are identified in the images with the help of given sketches and the measurement can be done in the same manner as that of tie points.
- (Bundle) block adjustment, which is carried out by a computer program, using image coordinates of tie points, image and object coordinates of GCPs and camera data as input, and determines exterior orientation parameters of the images and object coordinates of the tie points.

Automatic AT or AAT aims to minimize human interactions in these processing steps. Obviously, step (1) requires human knowledge and can hardly be automated. Step (4) is a real computational job and performed already without any human interaction. Step (3) is a semantic work, needs specific knowledge for identifying GCPs in images, and thus a full automation is still hardly realizable with available techniques of today although there are some successful attempts made for special cases, cf. [5, 7]. However, image coordinate measurement can be overtaken by digital image matching algorithms. Step (2) remains then the most laboured and time-consuming work in the whole procedure. Since tie points serve to geometrically connect neighbouring images and no specific features need to be recognized, a full automation of this step is possible.

Keeping this workflow structure unchanged and taking some digital photogrammetry specific preprocessing steps into account, we can make a classification of AT processing steps and work out a definition of AAT.

Processing step	Type	Mode
Block preparation		
• data collection	handworking	manual
• image digitization	(non-)semantic	manual / automatic
• block configuration	(non-)semantic	manual / automatic
• pyramid generation	computational	autonomous
• interior orientation	semantic	manual / automatic
Tie point determination	non-semantic	autonomous
GCP acquisition in images	(non-)semantic	semi-automatic
(Bundle) block adjustment	computational	autonomous

Table 1: Workflow of automatic aerotriangulation.

Table 1 shows classification and realization in an AAT workflow. In addition to automation of tie point determination and GCP acquisition, further steps in the block preparation can be accomplished automatically. As far as films are used as primary medium, digitization or film scanning is prerequisite for digital image processing. Equipped with high performance scanning systems, image digitization can be done also automatically, e.g. [20]. Block configuration deals with geometrical ordering of images in a block. Using flight planning systems or even better the Global Positioning System (GPS) for block flight, an automation of this step can be achieved as well. Digital photogrammetric processing is always confronted with a tremendous amount of data. For instance, a black-and-white aerial image scanned with a geometric resolution of 15 µm and a radiometric one of 8 bits amounts already about 240 MB. In order to speed up or sometimes well make the processing, a coarse-to-fine strategy is often applied.

This kind of hierarchical processing is usually based on image pyramids. Pyramid generation is computational and, therefore, does not need any human interaction. Photogrammetric computation is performed in the photo or image coordinate system defined by camera fiducial marks whereas digital image processing works with pixels. The interior orientation serves to establish the image-pixel relationship. It is semantic, i.e. fiducial marks must be recognized and measured. However, since fiducial marks are usually of a fixed simple pattern which is relatively easy to be recognized in an image, automatic processing is possible.

In summary, AAT has an autonomous tie point determination as core of AT procedure, allows a semi-automatic GCP acquisition in images and thus makes the best use of computer to support and mostly replace human operator to conduct the whole processing.

3. Thoughts and Strategies for Automation

3.1. The Idea of "Block as a Whole"

The main goal of aerial photogrammetric processing is to reconstruct 3-D terrain surface from a block of 2-D images and produces digital terrain model (DTM) and its follow-up products (e.g. contour lines), orthoimage and thematic information (buildings, roads, etc.) of the region covered by the block. Due to opto-mechanical limits of analogue as well as analytical instruments, conventional photogrammetric processing is usually based on stereo models. Drawbacks of this model-based processing are among others

- lack of global consistency control, e.g. results of two neighbouring models may differ from each other and, as a matter of fact, lead to problems for their connection;
- no full use of available information, e.g. only one image pair is observed each time, information from further neighbouring images is ignored;
- inconvenient handling, e.g. a manifoldly overlapping image must be put onto instrument as many times as overlaps, in addition, individual models must be connected afterwards.

Digital photogrammetry opens new possibilities to remedy these drawbacks, since here computer plays the central role and there are no any physical limits for operations, at least theoretically. In block adjustment, a block must be considered as a whole for computation because of limited number of available GCPs. Thanks to the development of computer technology, this kind of block-based processing can be realized by means of computer programs. In the same way, we can now re-conceptualize other processing procedures in digital photogrammetry as well.

The idea of "block as a whole" aims at a global thinking for operations and attempts to gain

- the best global consistency, i.e. there are no individual models for additional connection, the block is formed directly by connection of images which is further controlled by simultaneously using all possible information available;
- the best use of available information, i.e. the simultaneous use of all available information can not only support the consistency control mentioned above, but also optimally exhaust the information potential to reach a final goal, e.g. a hidden point on an image may, however, be visible on other neighbouring images;
- the best comfort for operation, i.e. the complete model level does not exist any more, which means for practice no additional model connection, no additional data storage and management, and no additional error sources as well.

Our intention is to reach the highest level of automation for photogrammetric processing. Obviously, the question of how to guarantee the reliability and robustness of an automated system is the most challenging issue for every system designer. The idea of "block as a whole" can strongly supports well establishing automatic or even autonomous procedures.

3.2. Principle of Image Connection

The task of AT is to reconstruct or form a photogrammetric block, where the complex is reduced to determination of tie points in images. Thus, for an AAT system, attempts are also focused on how to select and measure tie points automatically.

Conventional manual method concentrates on so-called standard positions in images, selects proper points and transfers them to neighbouring images. An obvious reason supporting this method is that the fewer the points measured, the less the labour work. A direct adoption of this point transfer method for AAT has to be confronted with following critical issues:

- Conjugate patch positioning: Image patches around standard positions are basic units for point transfer. Therefore, definition of really "conjugate" patches plays here the key role. A fine positioning of conjugate patches requires not only quite precise exterior orientation parameters of the images, but also a relatively accurate elevation model in the object space. This makes algorithmic realization very difficult and complicated. A fatal error source might come with an incorrect positioning that two patches are not conjugate, but matched to each other very well, because contents in the small patches can quite possibly be homogeneous.

- Patch content: The size of an image patch is small due to computational efficiency. Assuming that a patch be 1000×1000 pixels in size, the covered image area scanned with 15 μm will be 15×15 mm^2. Such a small patch can easily fall into an area where the image texture is too poor or unsuitable for matching, e.g. water, tree covering. Unfortunately, such kind of covering can quite possibly occur around standard positions on images in practice.
- Local control: Like in the case of manual method, the block distortion is still unavoidable if there are not enough GCPs available or measured in the block. The reason is that few number of small image patches can only give local controls over the block.

Following the idea of "block as a whole", we can look at the problem again from a global point of view. The goal is to form a block by connecting images, i.e. dealing with the whole image area instead of small patches. In other words, the whole area of an image is searched for possibly well-defined tie points. Two practical facts support this principle of image connection. First, tie points evenly distributed over an image intuitively present a stable geometric connection to its neighbours. Second, the texture appearance on an image is hardly foreseeable and concentrating on certain small areas to expect obtaining good tie points is, therefore, not very realistic for an automatic process.

Evident advantages come with this principle:

- Optimal use of information: Whatever an image looks like, tie points will be extracted from those areas where good texture exists. No prepositioning is needed and no special analysis of image content is necessary. This leads to an optimal use of the information provided by the image and the best connection to the neighbouring images.
- High reliability and robustness: The optimal use of information in an image also explores the best possibilities for connection. Locally poor texture will not affect the global connection. In addition, an efficient mechanism based on some global mathematical models (e.g. collinearity equations) can be incorporated to ensure the geometric consistency of the obtained tie points and, as a matter of fact, the reliability and robustness of the final results.
- Global control: Global area image connection instead of local point transfer can lead to a very strong interior geometric stability of the block. The block distortion can also be compensated optimally. Thus, it is to expect that the number of GCPs for the block adjustment might be reduced to a very limit and even more laboured work can be saved.
- Easy operation: Precise initial exterior orientation parameters of images are not necessary, and neither are elevation models. Only the general block information (e.g. strips, neighbourhoods or approximate projection centers) is required to run the automatic process.

3.3. Combined Image Matching

Digital image matching makes automatic measurement of conjugate points in images possible. Existing techniques for image matching can be classified into three categories (also cf. [6, 13]):

- area-based matching (ABM), where gray levels are matched using a similarity measure of cross correlation or least squares.
- feature-based matching (FBM), where point, line or area features are extracted and matched according to certain geometric and radiometric constraints.
- structure or relational matching, where structural descriptions of features are matched by comparing their topological and/or geometric properties.

Regarding to tie point determination in AT, some essential requirements must be met by an image matching algorithm:

- large pull in range,
- tolerable to scale and rotation differences,
- less sensitive to occlusions,
- accurate for measurements,
- possible for multiple image processing.

ABM delivers the most accurate matching results and is, however, very sensitive to occlusions. Some ABM approaches like the cross correlation don't care how good initial values are, but can only work well for cases where images don't differ much from each other in scale and rotation. The least squares matching (LSM) can tolerate some scale and rotation differences and even be tuned for multiple images, but requires quite good initial values. FBM approaches are a little bit moderate in accuracy, however quite capable of meeting the rest of the requirements above. Structure or relational matching is expected to be suitable for any cases, however, the presently proposed algorithms show a very high demand on computation time.

Obviously, a combination of FBM and LSM techniques may optimally meet the requirements above. In this case, a FBM algorithm serves to obtain initial values and LSM takes the responsibility for the fine measurement. This kind of combined image matching approach can also optimize the use of available information and the computation time for realizing the image connection (cf. section 4.2).

3.4. Exhausting Automation Potential

Semi-automatic GCP acquisition in images leaves the identification task to the human operator and uses image matching algorithm for coordinate measurement. Supposing that a GCP may appear in 6 images, all 6 images have to be searched by the human operator for the GCP. If there is quite a few number of GCPs of this kind, the human operator will still feel very tiresome. Thus, more comfort for this task is highly desirable.

Autonomous tie point determination following the principle of image connection opens another possible way to turn this semantic work more or less to a non-semantic one. The idea is that tie points evenly distributed over the whole image area can be used to define local transformation parameters to the neighbouring images. Given a position in an image, the approximate corresponding positions in the neighbouring images can be calculated via the local transformation parameters. In this way, human operator needs to identify and precisely locate a GCP in one reference image only and then a hierarchical multi-image matching algorithm takes care of finding its correspondences in other images.

4. System, Algorithm and Results

Based on the statements in the last two chapters, PHODIS AT was designed and developed. Details about the system realization and achieved results can be found in [4, 14, 16]. In the following, only some highlights around the system will be given.

4.1. System Structure and Workflow

Fig. 1 shows the system structure of PHODIS AT. In the center, there is a relational data base, which holds all kinds of input information and data as well as results of an AT block, and supports communication and processing among individual system components. The system consists of five components or procedures, i.e. block preparation, autonomous tie point determination, semi-automatic GCP acquisition, (bundle) block adjustment and block post-processing.

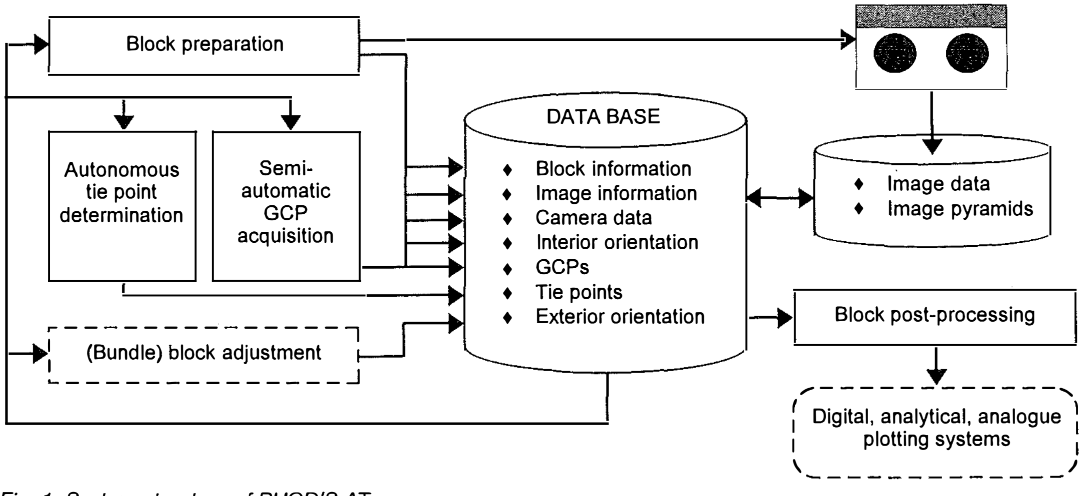

Fig. 1: System structure of PHODIS AT.

In addition to digital images, only camera data, GCPs and a list of approximate projection centers are primarily required by the system. The latter can be derived either from the log file of a flight planning system (e.g. T-FLIGHT) or simply by reading the flight plan. GPS measurements, if available, can make this kind of estimation more precisely, but are not necessarily required by the system. Based on these input data, the block structure can be defined and generated with the help of a special graphical editor. For practical reason, a block can be divided into subblocks, which can be handled independently and tied together by considering overlapping images. After image pyramid generation and automatic interior orientation, autonomous tie point determination and semi-automatic GCP acquisition can be started one after another or at the same time. Measurements of tie points and GCPs are then forwarded to an available program of bundle block adjustment for determining orientation parameters and object coordinates of tie points. For this purpose, the system is open for any popular commercial program packages or user-owned programs, because the photogrammetric practice has gotten accustomed to its own block adjustment programs since decades and it is not necessary to convince anyone to use an unfamiliar program again. Finally, obtained results are transformed to specific formats for image orientation on digital, analytical or even analogue (if necessary) plotting systems.

4.2. Autonomous Tie Point Determination

The procedure of autonomous tie point determination plays the key role in the whole system. It follows the principle of image connection and is realized by a coarse-to-fine combined image matching approach.

Fig. 2 shows the concept of this autonomous procedure. Image pyramids are divided by defining a so-called intermediate level into two parts. The upper part includes levels with small image sizes and lower resolution and the lower part the ones with increasing image sizes and higher resolution. Two steps are involved: Block formation, serving to connect images of the block together within the upper part of pyramids, and point tracking, trying to reach the highest measuring accuracy through the lower part of pyramids. The idea of introducing the intermediate level is to arrive at an optimal combination of the use of available information and the computation time. Thus, the intermediate level will be defined at that pyramid level, in which the tie point determination can still be carried out fast enough and from which enough tie points can be generated for a reliable point tracking.

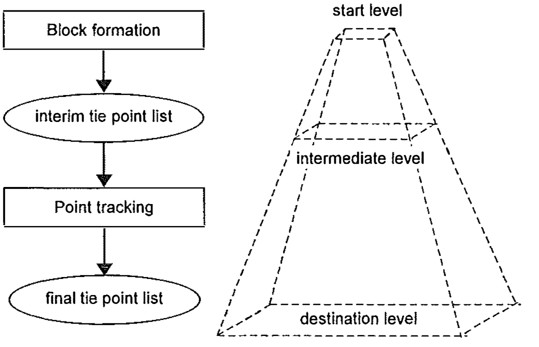

Fig. 2: Concept of autonomous tie point determination.

Fig. 3 illustrates the principle of block formation. Individual images are connected with their neighbours by a FBM algorithm. Point features are first extracted from each image by using an interest operator. They are then matched according to certain geometric and radiometric criteria. For connecting an image pair within a strip, relative orientation is used as the geometric model, where outliers in the matches are detected and eliminated by a robust bundle adjustment. A pair of images from two neighbouring strips is connected based on a model of robust affine transformation. Manifold connection is reached by checking shared features in reference images. The final result is a tie point list at the intermediate level, in which each tie point is provided with a unique name, a list of tying images and their measurements.

In order to precisely measure the image coordinates of a point in the tying images, LSM is carried out pair by pair through the rest of the pyramids (Fig. 4). Around a point pair at the intermediate level, a reference and a search window are defined. Six affine and two radiometric parameters of the two windows are determined iteratively. A match which also meets the condition of cross correlation is then declared as successful. An interest operator serves to find a point within the reference window which is proper for repeating LSM in the next lower pyramid level. At the end, the tie point list is updated with coordinate measurements in the original images.

The final results of the autonomous procedure are tie points being evenly distributed and accurately measured in original images.

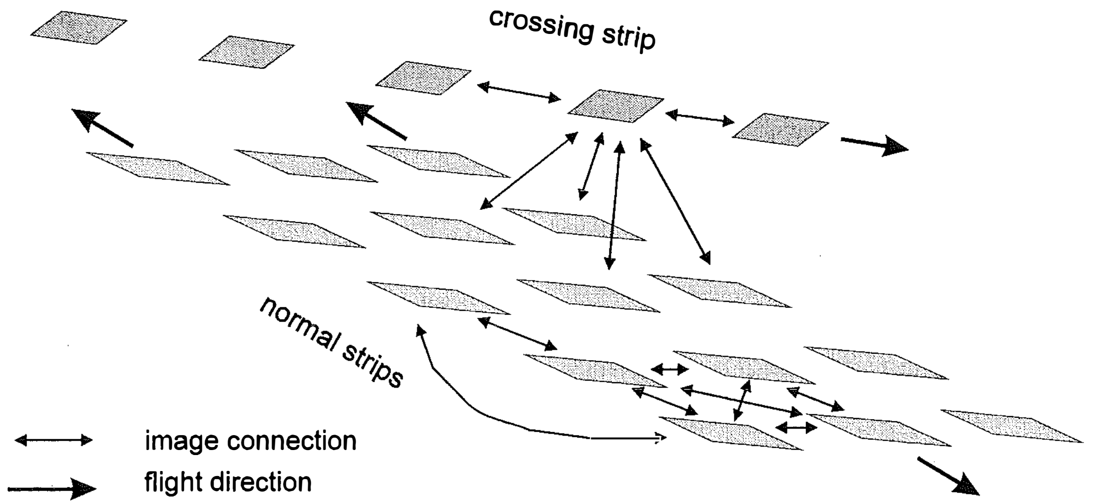

Fig. 3: Block formation.

4.3. Experiences

PHODIS AT is now in daily use in photogrammetric production. Results obtained by intensive tests using diverse concrete projects were presented in [4, 14, 16]. Report on the use of PHODIS AT in practice can be found in [8]. It has proven that an accuracy of 0.2 – 0.5 pixel size or better, the same level that a human operator can reach, can be achieved by AAT and the result is much more reliable than that of conventional AT thanks to the even distribution of large number of tie points (cf. Fig. 5).

Moreover, AAT is much more economic than conventional approach. Fig. 6 shows the configuration of the block Rocky Mountains. Some block parameters and results are presented in table 2 (cf. also [3]).

5. Conclusions and Outlook

The development of computer technology of today allows us to re-conceptualize photogrammetric processing procedures from local to global thinking. The idea of "block as a whole" has already led to great success of automatic aerotriangulation and is being extended to other automated processing procedures in digital photogrammetry [3]. An automated photogram-

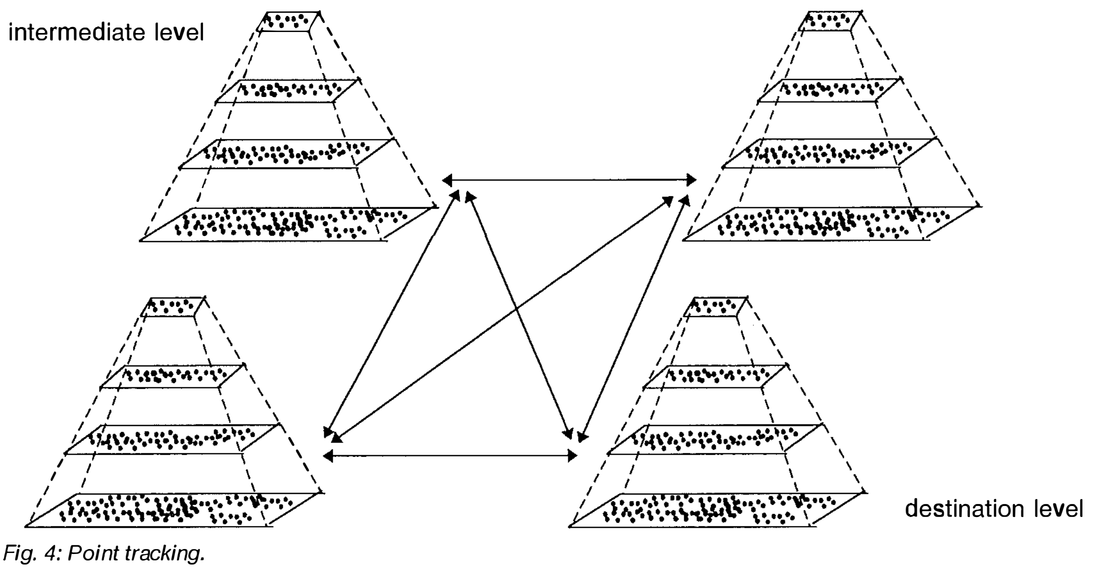

Fig. 4: Point tracking.

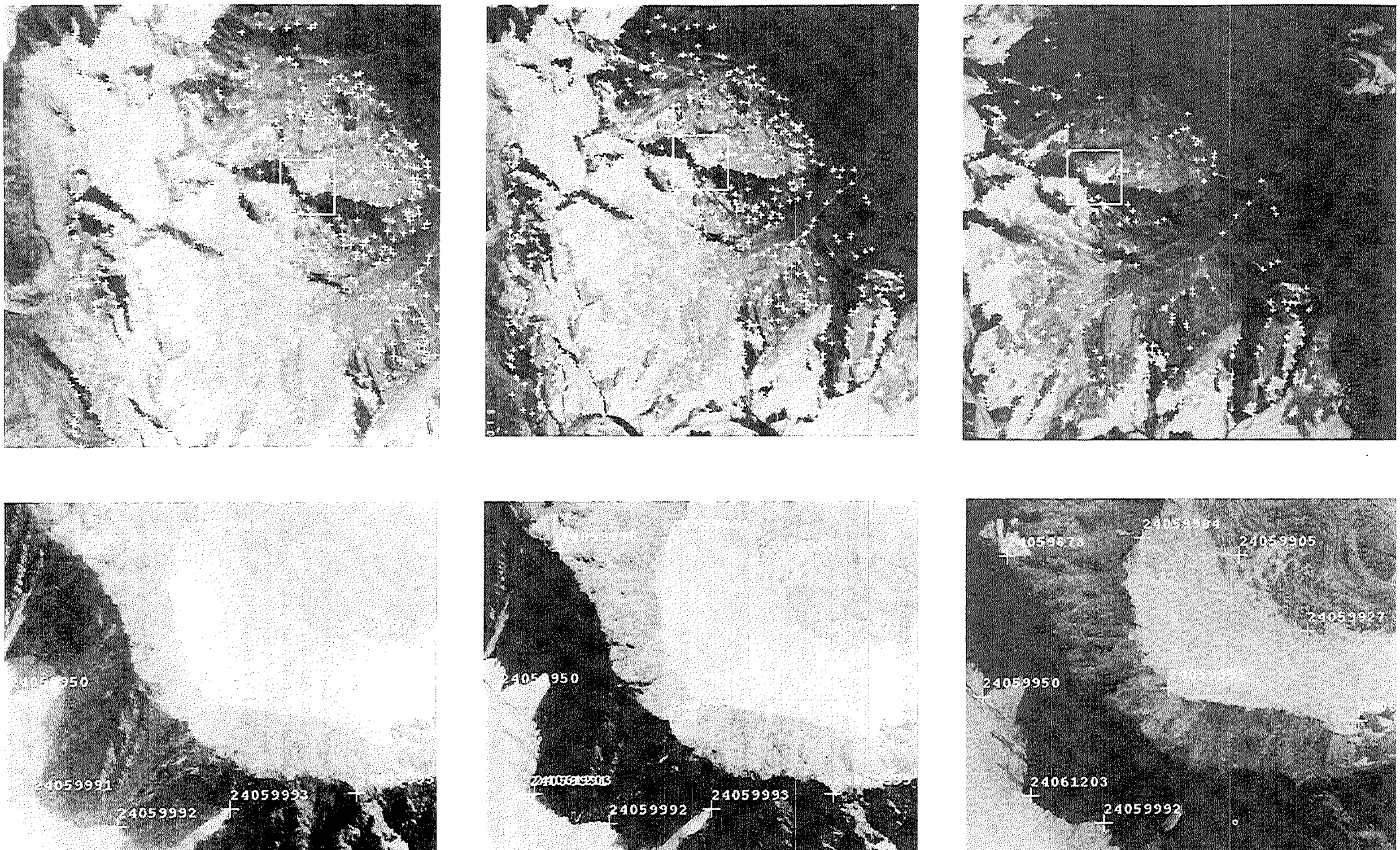

Fig. 5: Tie point distribution and detailed measurements in original images obtained by PHODIS AT, example of Alps Vernagtferner, Austria.

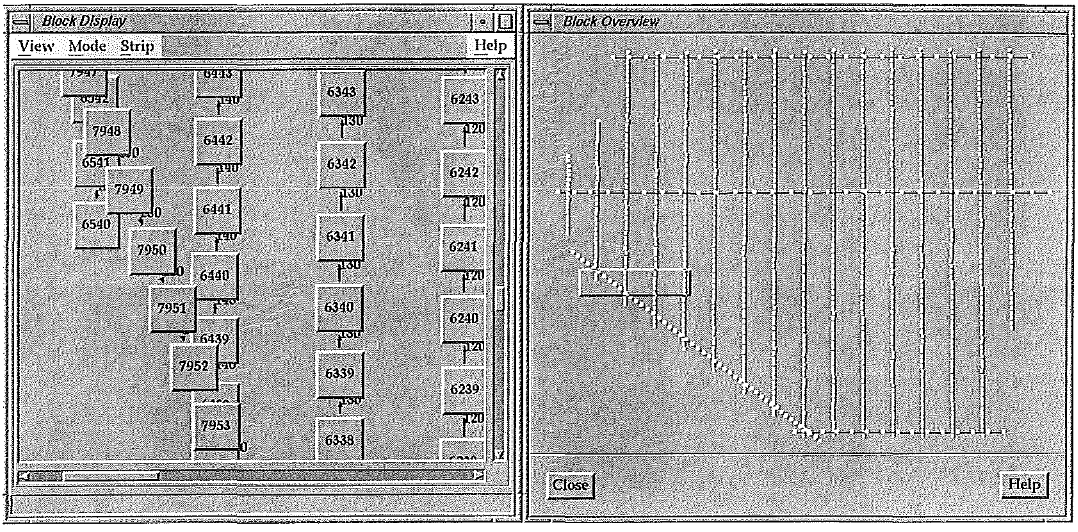

Fig. 6: Block display of Rocky Mountains, USA.

Region description	Rocky Mountains (elevation difference > 1000 m)
Number of normal strips	16
Number of crossing strips	4
Total number of images	1200 (black-and-white)
Resolution	28 µm (scanned by using PHODIS SC with SCAI)
Storage capacity	ca. 120 GB
Number of ground control points	21
Computation time for tie point determination	137 hours (ca. 6 days)
Total number of measurements	440000
Computation time for bundle block adjustment	19 minutes
Sigma naught σ_0	3.2 µm (ca. 0.11 pixel)

Table 2: Block parameters and results of Rocky Mountains, USA.

metric system which allows automatic image scanning, automatic aerotriangulation, automatic digital terrain or surface modelling and orthoimage generation as well as automated data acquisition for geographic information systems will become soon a reality [15].

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Notes on Digital Aerotriangulation and R&D Potential in Photogrammetric Applications

Xiaoming Xu, Graz

Abstract

Two aspects on the digital photogrammetry are discussed in this paper: (a) accuracy analysis, experience and the necessity of additional program on the automatic digital aerotriangulation (AT) are first described. Here not only the feedback of the automatic procedure from production but also some additional programs beside the commercial ones are explained in details; (b) On the base of one program package, "DAP" (Digitaler ArbeitsPlatz) the potential of Research and Development (R&D) in the daily production is discussed in this paper.

Zusammenfassung

Zwei Aspekte über die digitale Photogrammetrie sind Inhalt dieses Beitrages: (a) Analyse der Genauigkeit bzw. Bericht über die Erfahrungen und die notwendigen Zusatzprogramme für die digitale Aerotriangulation (AT) werden beschreibt. Dabei soll nicht nur das Feedback über das automatische Verfahren durch die Produktion sonder auch die Zusatzprogramme in Detail betonet werden; (b) Auf Basis des Programmpacketes „DAP" (Digitaler Arbeits-Platz) wird das Potential der Forschung und Entwicklung (F&E) für die tägliche Produktion diskutiert.

1. Introduction

For a dynamic developing city, like Graz, it is long enough for about four years to have a total new aerial photo to cover the whole city area. In order to bring these high-quality photos into photogrammetric production as soon as possible, aerotriangulation (AT) becomes a must step. In the year of 1992, when the digital aerial photos and certainly also the automatic triangultion procedure are not so popular as today, Graz has finished its AT with traditional analytical method. It was and is a time consuming and very patience-necessity job, but when everything well done, it gave and gives a reliable and precise result [1], [2]. Began in the year of 1994, the Graz City council, especially the department of Surveying has been trying to apply the digital aerial photo in production. This effort is now spreading into several directions, e.g. digital AT, digital orthophoto production, digital workstation (DAP- Digitaler ArbeitsPlatz) and 3D (three dimensional) city model. In later paragraphs of this paper digital AT and DAP will be described in detail, here some words about 3D city model may be given.

As one of the newest possibility from digital world, 3D city model is being used intensively by the department to present its surveying result in different application fields. It can used to display the past, the present and the future of the city parts during different discussions in live. Fig.1 shows an example. For city planning and administration, it is well known that the Virtual Reality (VR) plays more and more important figure. It can be used to display and analyse the spatial structure, the form of buildings and to visualise interactively alternative projects.

Nowadays existed 2D and 2.5D GIS (GeoInformationSystem) data are converted automatically into 3D city model [3]. The software GIS3D is now used for this purpose with very little operator intersection. But the digital facade photos