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A New Concept for Automatic Digital Aerial Triangulation

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ABSTRACT

This paper reports about a new approach to fully automatic aerial triangulation. The system concept incorporates the automatic derivation of tie point areas and the automatic matching of tie point clusters. The matching part is characterized by multiple image matching techniques carried out hierarchically through image pyramids. The image orientations and the ground coordinates of the tie points are estimated simultaneously. Preliminary results are reported, indicating the practical applicability of the approach.

1. INTRODUCTION

Automatic aerial triangulation is currently one of the major issues in digital photogrammetry. Today, digital photogrammetry is reported to be economical in small scale applications like DTM extraction and orthophoto generation (Colomina and Colomer, 1995; Miller, Walker and Walsh, 1995). Aerial triangulation however is mostly carried out in the traditional way by using the analog images and realizing the point transfer with the analytical plotter in combination with an appropriate bundle block adjustment program. This is a well established and a highly optimized technique which nevertheless has technical limitations. It remains purely interactive and hence costly because of the expensive man power which is especially needed for the time consuming block preparation. Undoubtedly, a fully automatic procedure for aerial triangulation will push digital photogrammetry to a new level of economical efficiency. In view of the attractive prospect, that automatic aerial triangulation, DTM extraction and orthophoto generation will basically become automated in a single process, a drastical breakthrough appears to be possible, which will mark a paradigm jump in digital photogrammetry (Ackermann, 1995).

Automatic aerial triangulation is here basically understood as an autonomous batch process, which intelligently pre-selects tie point areas and subsequently applies a matching strategy for automatic point transfer. This is a clear distinction to so-called semi-automatic systems for aerial triangulation, which are meanwhile available on almost all digital photogrammetric workstations released during the last years. They are basically interactive and provide image matching tools for semi-automatic measurement of manually pre-selected tie points and built-in bundle adjustment procedures for on-line triangulation purposes as well. A considerable performance of 8 minutes per image is reported (Beckschäfer, 1995). Users like the flexibility of such systems to define and optimize the location of tie points by handling the images on the screen of the softcopy workstation. Expensive man power however is needed during the entire process of point selection and point transfer.

There are two important technical developments to be mentioned which influence today's automatic aerial triangulation. First, as far as the image matching strategy is concerned, it becomes evident that it is not neccessarily the best strategy to match only single image points with maximum precision in the 9 standard positions. It is much more advantageous to match point clusters (e.g. 10-20 points) by means of feature extraction and feature-based matching techniques. In general, such a point cloud measuring strategy appears as a new measuring philosophy which can successfully be applied in various fields like surface reconstruction (DTM, industrial free-form shapes), photogrammetric deformation analysis, and aerial triangulation. Experiences in the mentioned application fields have clearly shown that a large number of matched points, provided by feature extraction and feature-based matching, leads to high redundancy. Thus, a high accuracy potential, an internal quality control based on reliable statistical values, and an effective blunder detection byusing robust statistics becomes

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possible. Nevertheless, area-based matching techniques for high point precision can still be regarded as an useful complementary matching tool to improve the point precision wherever neccessary.
The second important improvement in the field of aerial triangulation is the highly effective establishment of GPS technology. GPS-based flight navigation systems provide regular block forms. Furthermore, the exposure centres of the aerial cameras can be pre-determined by GPS positioning techniques with an accuracy of 30 m or even better. Today, also INS techniques are additionally applied, leading to an accuracy of the camera attitude in the order of 0,5 degree or better. In view of their powerful potential, both techniques could be highly useful to simplify the critical initialization of the tie point areas which the kernel of an automatic aerial triangulation system has to start from. At least, the GPS method might become a standard in future.
We also have to recall at this point two developments for automatic aerial triangulation. Schenk and his group at Ohio State University have successfully installed an experimental system which conceptually includes the automatic derivation of the Gruber point locations and the hierarchical point transfer in image pyramids (Schenk, 1995; Toth, 1994; Toth and Krupnik, 1994; Schenk and Toth, 1993). At Stuttgart University a system was developed that has reached an operational status (Ackermann and Tsingas, 1994; Tsingas, 1992).
The concept described here includes the automatic derivation of the tie point areas and a hierarchical matching of tie point clusters as well. The kernel of the system is characterized by a robust multiple image matching of feature points and a simultaneous estimation of the orientation data. Editing and visualization functionalities are added to the system to provide operational workflow.

2. BASIC CONSIDERATIONS

2.1 Initialization problem

A system for fully automatic aerial triangulation has principally to deal with the appropriate selection of tie point areas and the subsequent point transfer by means of multiple image matching techniques. Tie point areas are here to be understood as patches at the 9 standard positions of an aerial image, also known as Gruber positions. The initialization of those tie point areas has to be provided accurately enough to guarantee a successful automatic point transfer based on the matching strategy being applied. Let us presume a reasonable pull-in range for the feature-based matching method of say 8 pixels. This implies, that, at a coarse pixel resolution of 2 mm, the tie point areas must be known within about 1,5 cm. It may be recalled at this point that the true image positions of the 9 standard tie point positions depend on the exterior orientation and the terrain surface as well. So, how can we pre-determine the locations of the tie point areas with sufficient accuracy? One possibility is to take GPS and INS data into consideration. If we assume an accuracy of the camera exposure positions of 30 m - provided by GPS flight navigation systems - and the camera attitude of about 0,5 degree - provided by INS techniques - , the total displacement of a tie point area against its nominal position remains within 1 cm in image scale. Actually, this corresponds quite well to the requirements implied by the pull-in range of the feature-based matching method, assuming a hierarchical procedure which starts at such a coarse pixel resolution. This simple estimate however is only true for flat terrain. In case of hilly or mountainous terrain the relief displacement comes into play. Its x,y components amount to about 2 cm at height differences of 20 % of the flying height, which means only about 150 m at an image scale of 1:5000, for instance. Thus, a given DTM or a crude DTM in combination with GPS and INS would simplify the critical initialization procedure of the tie point areas. However, it cannot generally assumed that a DTM is available in most applications. In addition, GPS and especially INS may not neccessarily be applicable in all projects. Thus, other methods operating directly on the digital images have to be pursued in order to guarantee a fully automatic procedure that is suitable for all cases. In our approach we use the automatic relative image orientation as a basic technique to find the adequate tie point areas in the block. Once the tie point areas have been properly identified, the automatic point transfer is applied straight forward through an image pyramid.

2.2 Input data

The system is generally designed to require as little pre-knowledge about the block as possible. However, some assumptions and input data are required to start from. Control points and the camera calibration data are mandatory. Some initial block data are at least needed like a flight index map, data for the overlap percentage, the image scale, the flying height and the image sequences in the strip. Those geometrical data provide crude orientation values of the images. They can be substituted by orientation values derived from GPS and INS observations, if available. As already pointed out in 2.1, an existing crude DTM of the block area with a grid width of say 1 mm in image scale could be used in combination with GPS and INS data to initially locate the tie point areas more precisely in case of undulating or mountainous terrain.
The images to be processed should be scanned at a pixel resolution of 15 µm or 30 µm, preferably in combination with an overview image of 480 µm pixel size. The interior orientation should be provided together with the scanned images, although this still depends on the scanner type being used. The scanning resolution of 60 µm might become interesting in view of the high accuracy to be expected even at such a coarse pixel resolution. The design of the system assumes, for the time being, that all digital images, or at least a large percentage (e.g. 50 %), of the block are directly accessible on the softcopy workstation or over a network for best data access performance. This is technically no restriction, since today's softcopy workstations can be equipped with disk arrays of up to 75 GB net disk space, for instance, making up to 1000 30µm-images easily available. Also, data managment systems for digital images which archive the images back and forth might become available at reasonable prices.

2.3 General system features and goals

The presented approach for automatic aerial triangulation includes the following general features:

1) manual or semi-automatic measurement of control points,
2) manual or semi-automatic measurement of fiducial marks,
3) automatic initialization of tie point areas,
4) automatic matching of tie point clusters in tie point areas,
5) integrated bundle block adjustment for automatic point transfer,
6) manual or semi-automatic measurement of problem areas.

The approach is mainly characterized by a preparation part and the kernel system in which the automatic point transfer is carried out by using an integrated bundle approach. The preparation comprises, besides parameter editing, the manual or semi-automatic measurement of the control points (1) and of the fiducial marks (2), if the interior orientation has not already been applied to the images. Although the initialization of the tie point areas (3) is intended to be fully automatic based on an automatic relative orientation applied to image pairs, other complementary techniques are possible like the usage of GPS and INS, eventually in combination with a DTM. The results of this first major part are preliminary orientation data of the images and the locations of the tie point areas given in object space as X,Y,Z-coordinates. The kernel system uses this as input data and applies the automatic point transfer (5) through the entire image pyramid by matching tie point clusters (4). The system incorporates of course an interactive part (6) for manual or semi-automatical editing of the block in areas where the automatic procedure stopped or reported a weak block adjustment result. The final results are the orientation data of the images and the adjusted X,Y,Z-coordinates of the tie points.

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Let us also address the overall goals of the presented approach. The accuracy of the automatic aerial triangulation will meet the requirements of a standard aerial triangulation with σ_0 . 7 µm. It is to be expected, that at least at 15 µm pixel size the conventional requirements of high precision aerotriangulation (with σ_0 . 3 µm) can be achieved, although at 30 µm pixel size best accuracy results can be expected (Ackermann and Tsingas, 1994). The time performance of the system will be in the order of 6 minutes net computation time per image and better. The key idea of the approach is to extract and match point clusters in the tie point areas by means of feature extraction and feature-based matching techniques. The automatic point transfer is realized on multiple images by estimating the orientation parameters of the images and the ground coordinates of the tie points simultaneously. This is a clear distinction to other aerial triangulation systems released so far which apply the individual matching strategy only to single tie point areas. The approach uses the ray intersection of multiple bundles as the geometrical matching criteria instead of the well-known affine transformation, which provides a sufficient geometrical matching model only in flat terrain. Thus, the perspective model also gives more flexibility in hilly and mountainous terrain. Since point clusters are matched, a high redundancy is attained which leads to high accuracy and reliable quality control. Blunders are detected by means of robust statistics being applied in the matching process.

3. APPROACH TO AUTOMATIC AERIAL TRIANGULATION

3.1 Preparation

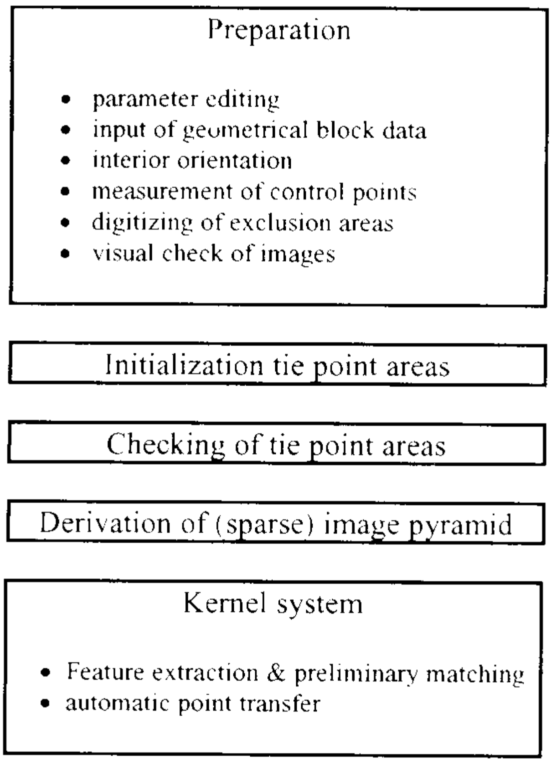

Figure 1: General flow chart in AAT-system.

The roughly described approach to automatic aerial triangulation will now be explained in more detail. The general flow chart is shown in figure 1 and comprises 5 characteristic steps. The preparation part of the system includes the editing of control parameters and the input of geometrical block data such as overlap conditions along and across the strips, the flight index map, the flying height, the image scale and the camera parameters. Furthermore, interactive work is neccessary for the interior orientation of the images and the measurement of control points. The latter task will mainly remain interactive unless the control points are signalized. In such exceptional cases the automatic measurement of control points might become feasible (Gülch, 1995). Exclusion areas, in which no automatic measurements are permitted, can be defined in the images by polygons. This is also the level at which the tie point areas derived from the flight index map and the overlap conditions can be checked and eventually edited. However, this should be the exceptional case as long as the interaction work is to be kept comparatively small. In general, the initialization of the tie point areas are automatically to be derived which is dedicated to step 2 of the flow chart in figure 1.

3.2 Initialization of tie point areas

The goal of that part of the system is to provide sufficiently precise tie point locations in all images of the block that guarantee, even in the presence of large relief displacements, a successful matching of

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the tie point clusters in the subsequent automatic point transfer. In general, the method operates solely on the digital images which are given. As a result, crude data for the orientation parameters and the DTM are calculated. The tie point locations are derived by analyzing the overlapping conditions in the block DTM.

The method is based on an automatic relative orientation procedure which is applied to all image pairs overlapping with 60 %. The standard 20 % sidelap is considered to be too small for a successful automatic relative orientation. However, in special applications with larger sidelap of say 60 % the automatic relative orientation will also be applied across strips. For each image pair a model DTM is derived at a pixel size of 480 µm. The process operates hierarchically in a small image pyramid which is directly derived from the 480 µm overview layer. The grid width of the model DTM is set equal to about 5 mm or to 10 pixel, respectively. The derived DTM is interpolated from several hundred automatically matched model points. Since the single model DTMs are calculated separately, they have to be tied up by finding well-suited tie points in the overlapping areas of two neighbouring stereo models. Once those tie points have been found along and across the strips, a complete block adjustment can be applied using all preknowledge about the block available so far. These are in first instance the initially measured control points from step 1. GPS camera station data can be used for stabilizing the block adjustment as well. The results of the block adjustment are image orientations based on an average image point precision of 0.5 - 1 pixel. The related tie point precision of 0.25 - 0.5 mm is sufficient to sucessfully start the point transfer in the kernel system at a pixel size of 240 µm, i.e. on the next lower level of the image pyramid.

The block DTM is calculated by using the model DTM points which after the block adjustment refer to the ground control coordinate system. It is now quite simple to derive the tie point areas in object space from the orientation data and the DTM. DTM areas with maximum image overlap conditions are marked as the local tie point areas. Thus, the tie point locations are given in object space as X,Y,Z- coordinates with attributes indicating all images in which they actually appear. The same procedure can be used to derive the tie point areas if GPS data, INS data and a DTM are provided in advance. At this point it is also possible to define more tie point areas rather than the 9 standard Gruber positions for a block adjustment with additional parameters. The tie point areas are either visually checked and edited, or directly used in the automatic point transfer of the kernel system, together with the orientation parameters and the DTM.

3.3. Visual checking of tie point areas

Basically, once the tie point areas have been adequately found by the proposed method in step 3, the entire process of automatic point transfer through an image pyramid can be invoked. However, we conceptually establish here at this point a visual check of the tie point areas, independent of whether needed or not. Since the result of step 3 is a complete block adjustment, the visual check may be assisted by the block adjustment report about possible weak block areas indicating incorrect tie point areas. Thus, it is not neccessary to scroll through the entire block in looking for mismatches in the tie point areas.

3.4 Generation of image pyramid

The main reason for postponing the derivation of the image pyramid to this point is the idea to restrict the generation of the image pyramid layers to the individual tie point areas in which the process of automatic point transfer actually takes place. This means, that only small portions of digital images are subsampled in each image pyramid level which constitute altogether a sparse image pyramid structure. The size of the single image patches in each level is in the order of 3-4 cm square, depending on the size of the matching window to be applied in the automatic point transfer at the tie point areas. This procedure considerably saves disk space, compared to the amount of pixels which a complete image

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pyramid would imply. The scale between the image pyramid layers is kept constant and is preferably to be set equal to 2 or 3. However, it might be neccessary to create a full image pyramid structure in case an integrated DTM generation process is envisaged. Another interesting option would be to match additional image points in the entire image area for the purpose of a block adjustment with additional parameters. The process of creating image pyramids is algorithmically very simple, and it is only a matter of the process options whether a sparse image pyramid will be created or not.

3.5. The kernel system

The kernel system establishes the automatic point transfer and starts at the coarse image pyramid level of 240 µm by using the result of the initializing step. The block is divided into substructures which are defined by a subset of images on which the matching strategy is applied simultaneously. The integrated bundle solution guarantees the verification of homologous points and estimates the orientation parameters for all images of a substructure. From this point of view the matching part of the kernel system can be considered as a multiple image matching procedure which matches image point clusters of several images in one single adjustment process.
The main objective of the matching strategy is the estimation of precise and reliable orientation parameters rather than the realization of a maximum number of best multiple point matches. In other words, we are accepting to some extent incomplete tie point connections, as long as the integrated bundle solution reports an expected image point precision of about 0.3 pixel and indicates no other difficulties.
After processing all substructures in one image pyramid level, all matched points can basically be checked by a complete integrated bundle block adjustment providing orientation parameters for the entire block. Those orientations together with their covariances are used in the subsequent image pyramid level.
The entire process of the automatic point transfer in the kernel system can be subdivided into the following steps:

a) Automatic setup of substructures consisting of several overlapping images.
b) Feature extraction in all tie point areas of the substructure.
c) Feature-based matching in all image pair combinations.
d) Searching of potential multiple matches by using heuristic algorithms.
e) Verification of the preliminary list of homologous points by applying a robust bundle approach with simultaneous estimation of orientation parametersfor all photos constituting the substructure.
f) Linking of substructures to the entire block.

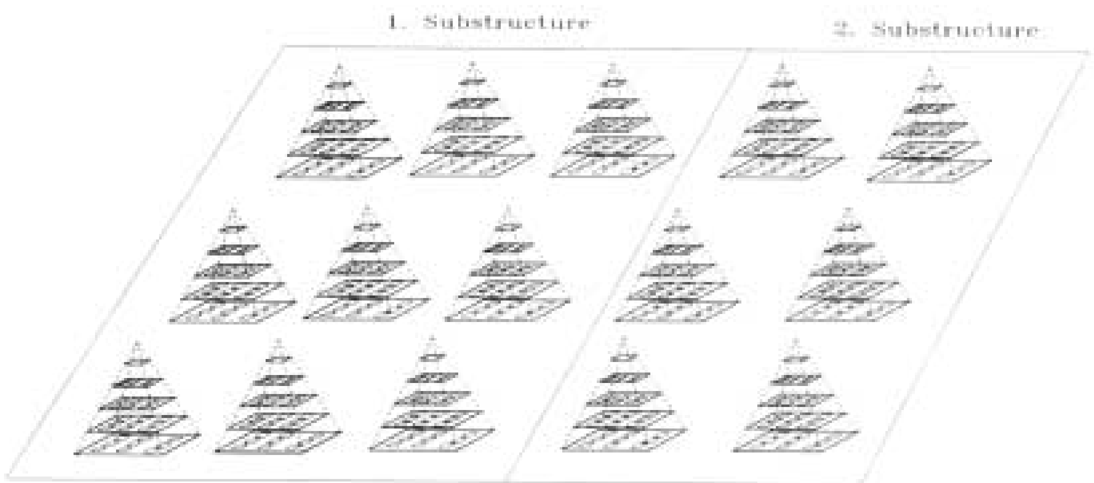

Figure 2: Exemplary substructuring of a block constituted by a set of digital image pyramids.

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The substructures are simply defined by a number of images to be processed simultaneously (Figure 2). The features are extracted in each tie point area by using the Förstner operator (b) in a suitable window of 40-60 pixels. A subsequent preliminary matching procedure applied to all image pair combinations creates a list of possible homologous points. The correlation coefficient, the interest value and the sign of the grey value gradients are used as iconic matching criteria. Also, the epipolar lines derived from the image orientations are taken into consideration as geometrical constraints. The preliminary list of homologous points only refers to image pairs and includes some mismatches which have to be analyzed and eliminated later on in the subsequent robust matching strategy (e). Usually, between 20 and 40 preliminarily matched point pairs are found in the matching window. Multiple matches are set up by a heuristic search (d) which leads to a graph representing a hypothesis about them. Also, this set of multiple matches contains mismatches. The heuristic search guarantees a linear increase of processing time in dependence of the number of the matched features.
The orientation parameters of the images can be introduced as weighted observations into the robust estimation procedure (e). They are essential for the convergence of the bundle solution, especially in case that the substructure has to be adjusted locally without control points. Mismatches are eliminated by robust statistics and problem areas are marked. The robust bundle solution leads to about 100 tie points per image or more. New tie point areas for the next image pyramid level are derived by using statistical image information and geometrical information of the bundle block estimation.
The primary matching strategy of the system approach is based on the idea to match a large number of feature points in the tie point areas. In poorly textured areas the number of image point matches can decrease significantly. Therefore, the system automatically applies in such cases after the block adjustment the area-based matching method in order to improve the precision of the single image points. The bundle block adjustment is then reinvoked using the more precise tie point measurements and the result of the previous block adjustment.
The final process (f) realizes the important link of all substructures to a complete block by introducing block unique point numbers for all multiple point matches, if the entire block cannot be processed in one single substructure. This technique guarantees that blocks with unlimited size can be handled. Furthermore, the interactive block editing - if at all neccessary - becomes easier since only the substructures located in weak block areas have to be reprocessed by using additional measurements of new tie points.
The final results are the orientation parameters for all photos of the block and the ground coordinates of the tie points. A separate final block adjustment should not be necessary, nevertheless it is conceptually integrated, if needed. There may be cases that the terrain coordinates of special natural objects are of interest. Such points can be measured in the photos and ground coordinates can be derived by a simple ray intersection, using the orientation parameters of the block adjustment.
The DTM is optionally refined in the tie point areas in order to describe the terrain surface more accurately. If a complete DTM generation is requested for the entire block area, the DTM is successively refined using rigorously all overlapping images with multiple image matching techniques. Such a DTM derived from more than two overlapping images with 60 % sidelap, for instance, will be of higher quality in terms of reliability and accuracy than DTMs generated from a standard stereo model.

3.6 Interactive measurement of tie points

Although the system is designed to process fully automatically the aerial triangulation, it also incorporates editing and visualization functionalities. This is especially needed if for some reason the block adjustment fails in some substructures. In such a case, all measured image points are retrieved from special data files and displayed for checking and editing. Multiple image matching tools can be used to measure manually or semi-automatically erroneous or new tie points wherever neccessary.

Once the weak areas have been checked and corrected by additional measurements, a new block adjustment for that substructure can be invoked.

4. PRELIMINARY PRACTICAL RESULTS

The described system is currently under development at INPHO company with respect to all system features mentioned in 2.3. So far, we can report about preliminary results which were attained with a subset of 12 digital images taken from the OEEPE test block FORSSA. The kernel system ran successfully through a complete image pyramid starting from 480 µm down to 30 µm pixel size. The block adjustment, reported in each pyramid level, confirmed the expected internal precision of the image points between 0.3 and 0.4 pixel. The system successfully matched point clusters with 20 and more tie points. Also, the total computation time per image was in the expected range of about 5 minutes. We used a standard SGI workstation equipped with the R4000 MIPS processor. Those results are preliminary, referring to internal system tests, as needed during the program developments. They are, however, very promising and confirm the expectations. The system is going to be tested very thoroughly. Results of controlled tests will be presented during the Photogrammetric Week, 1995.

5. CONCLUSIONS

We have presented a new approach to a fully automated system for aerial triangulation. The key idea of the kernel system is to match point clusters in multiple images by the technique of a bundle solution. Also, the system automatically derives the initial tie point areas by an automatic relative orientation technique.

Digital photogrammetry becomes more and more applicable and acceptable and has reached a considerable degree of automation. Automatic digital aerial triangulation will certainly improve the productivity significantly. We also have to keep in mind that other related subprocesses like the interior orientation (Schickler, 1995) and the measurement of control points (Gülch, 1995) are or will be automated. Thus, the long process chain from the digitization of the images to the generation of DTMs and orthophotos becomes basically fully automated. This prospect is very promising and can be realized soon.

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