EXPERIENCES WITH AUTOMATIC AEROTRIANGULATION

Karsten Jacobsen
Helge Wegmann
Institute for Photogrammetry and Engineering Surveys
University of Hannover
Nienburger Str.1
D-30167 Hannover, Germany
FAX 01149 511 762 2483
Email: karsten@ipi.uni-hannover.de

ABSTRACT

The determination of tie points for a block adjustment by means of automatic aerotriangulation is starting now for practical applications. But there are more problems than expected. At first the operationally is limited, one product requires very precise approximate photo orientations and another takes not care about a sufficient equal distribution of the tie points causing gaps in the photo connection. In addition also the accuracy of the results are limited caused by moving shadows used as tie points and the negative effect of using mainly edge points. The excellent inner accuracy of the photo orientations based on the results of the automatic aerotriangulation has nothing to do with the outer accuracy determined with independent check points. But nevertheless with improved software, results are achieved which can increase the economic situation of the photogrammetry.

INTRODUCTION

The manual measurement of tie points for a block adjustment is time consuming even if it is computer supported. With the digital photogrammetry there is a possibility of an automation. Interactive methods of aerotriangulation are operational and used in practice since some years, but they still require the human operator for the identification of tie points in a start image. With automatic aerotriangulation the human operator only has to measure the image coordinates of control points, the tie point determination and also the block formation will be done automatic. An additional computer supported template matching of the control points can be done only with very large artificial targets, but usually it will not be economic.

The automatic aerotriangulation is starting with operational use, but there are still some limitations and especially for large scale it will not be more accurate than the existing manual measurements and the interactive method even if the

inner accuracy of the image orientations is shown with very small standard deviations caused by the high number of points. But the data acquisition can be more economic.
Even if some programs for automatic and interactive aerotriangulation do have the possibility of a block adjustment, because of the limited functions this will not avoid a final bundle block adjustment. The available programs are limited with the possibilities of automatic error detection and with the possibility of a combined block adjustment with coordinates of the projection centers determined by kinematic GPS-positioning.

PROGRAM MEPAS

In the University of Hannover, the program MEPAS has been developed for image matching. There are two components, MEPAS-IC for the creation of a digital height model based on 2 images and MEPAS-AT for automatic aerotriangulation. In general both versions are based on the same basic concept, but the organization is quite different. For a digital height model a high number of points is required, this can go up to 200 000 points in a model and for aerotriangulation the connection of a higher number of images is important. Several investigations have been made with MEPAS-AT, but also results from PHODIS-AT and Match-AT are available.
Like similar programs, MEPAS is using image pyramids to avoid problems with the start information and to improve the processing speed. Depending upon the original pixel size, up to 6 levels of the image pyramid are used. That means for example from the original size of 19 200 pixel in one direction, the image is down-sampled over 9600, 4800, 2400, 1200, 600 to 300 pixel. In the last reduced image only the major features are available, which makes it more easy to identify the general relation between the images. This relation is transferred later on to the lower levels of the image pyramid and will be improved from level to level. The final result is only based on the lowest level of the pyramid with the full resolution. This procedures solves the problems of approximations and reduces the computation time drastically.
In MEPAS after a filter process edges are identified. The edges are reduced to lines with a width of one pixel, small gaps are filled and very short edges are removed. Based on this, image regions are identified, each region has a limited range of gray values. With this information the relation between neighbored images are identified. This corresponds to the vision of the human, also the human will identify at first larger image regions and is comparing this with the overlapping image. In general MEPAS doesn’t require approximate information about the relation of the images, even if the images are rotated by 90°, the relations can be identified, but this takes a lot of computation time. By this reason the operational version of MEPAS is using approximate image orientations and an accuracy information about the specified values.

On the edges of the regions points are isolated which can be used as tie points. Depending upon the used control values, the number of points is increased from pyramid level to pyramid level. If the expected number of points will not be reached, a densification will be made in higher pyramid levels.

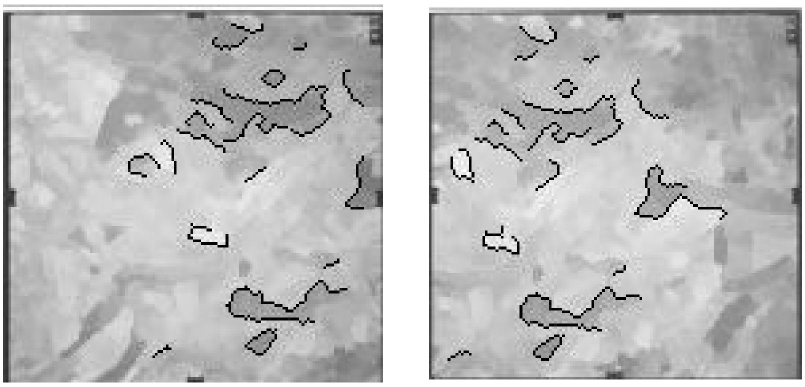


fig. 1: image regions with overlayed edges, highest pyramid level

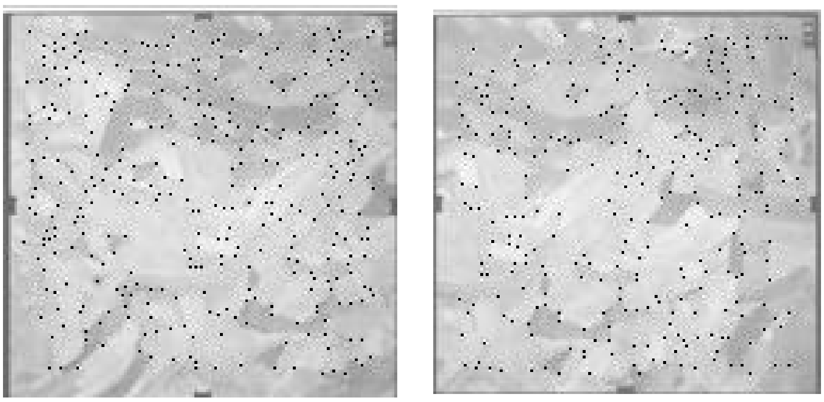


fig. 2: identified points in the highest pyramid level

In general we do not have points in the images, because a point doesn't have a dimension, we only do have areas with changing gray values or templates. The information about the gray value changes or corners of edges or even symmetric objects is reduced for the mathematical handling to a point. The "points" selected by the described method are identified only with the pixel address. For a more precise matching a correlation and a least squares matching will be made. The problem of the limited radius of convergence for the least squares matching does not exist if the "points" have been selected as points located on edges and are improved by correlation.
The exact relation of the points in neighbored images is checked by a 9-parameter transformation with 8 unknowns, this corresponds to a relative

orientation without knowledge of the inner orientation. That means, corresponding points are located on corresponding epipolar lines. The location of the position on the line is controlled also by the neighbored points, corresponding to a location in approximate the same height level. The relation is not only checked within a flight strip, also the neighbored flight strips are respected.
As control data following parameters can be specified:

- size of search and pattern matrix for the correlation and limit of correlation values,
- size of search matrix for the least squares correlation and iteration limit information,
- difference of gray values for the structure matching,
- relative accuracy of the given exterior image orientation [% of the base length],
- smallest number of pixel of the highest pyramid level,
- smallest number of tie points per image.

Without specification the default values are used.

RESULTS

Several blocks have been handled with MEPAS. A major problem is the required disc space. A usual aerial photo does have a resolution of 40 lp/mm, corresponding to a pixel size of 12 µm or 19 200 x 19 200 pixel per photo. For an 8-bit-image (black/white, 256 gray values) this corresponds to 368 Mbyte. Together with the image pyramids 480 Mbytes are required for each image. In the case of the typical medium size block Essen with 111 photos, 53 Gbyte are required in total. Of course this can be handled today but nevertheless it is causing problems. No program is using color images for the automatic aerotriangulation because there is no advantage and the information contents is still not the same in all spectral ranges, especially in the blue range the information is limited. There is also the question if really a pixel size of 12 µm is required. Different tests have shown only a negligible loss of accuracy for photos digitized with 24µm pixel size. By this reason for all blocks a pixel size of 24µm has been used, reducing the required disc space by the factor 4. With 12µm pixel size a more strong filtering was required showing also the tendency of a limited advantage of the very high resolution. This was indicated also by a small block digitized with an image scanner out of focus. The block has been digitized again with the correct scanner calibration, producing images with better contrast. But finally the result was better with the a little blurred images, showing also the requirement of a filtering which will be done within the program.
In the case of the first tests not a sufficient disc space was available for handling all images of a larger block. By this reason the blocks have been subdivided into overlapping sub-blocks. Because of the same method of point

selection corresponding points were determined in the overlapping area but with different point numbers. So at first a bundle block adjustment was computed with the original data with an image connection just based on control points. After the block adjustment with the analysis program BLAN of the Hannover program system BLUH identical points with different point numbers, but approximately the same location have been identified. This information was used for an automatic point renaming and the block with the now correct tie was computed again.
The block Essen was digitized with the Wehrli Rastermaster RM1 with a pixel size of 24µm. The preparation of the block including the measurement of 277 control points took 25 hours with OrthoMax. Such a high number of control points is usually not required, they have been used mainly for test purposes. For the automatic aerotriangulation with MEPAS-AT 11 hours were required on a SGI Indy R4400SC.

number of photos	111
number of ground points	49 324
total number of image points	109 301
number of points per photo	mean: 985 min: 405 max: 2107

table 1: technical data block Essen

number of ground points	41 099	6 585	1 090	397	103	24	17	9
determined in photos	2	3	4	5	6	7	8	9

table 2: number of photos / ground point, block Essen

figure 3: configuration of block Essen with selected points

The block Essen is typical for a usual block handled by MEPAS-AT. The mean value of 985 points per photo is totally sufficient, in other blocks up to in the mean 2500 points per image have been selected. As it can be seen in figure 3, the points are not equally distributed, there are small areas with gaps, caused by limited variation of gray values. Such areas should be avoided, also the human operator will not use it.

83% of the points are available only in two images (table 2). Of course it is better to have the points identified in a higher number of images, but this is not causing a problem because the connection is not available in the same way like in manually measured blocks. Several points, identified only twice are located in photos of different flight strips, this can be seen in the left hand side of figure 3, where points are located only in one image of a flight strip. By theory it is possible to connect a block in this way only with points just located in 2 photos.

	STRIP	N	STRIP	N	STRIP	N	STRIP	N	STRIP	N
STRIP 1 CONNECTED TO	2	167	6	1228	7	1678				
STRIP 2 CONNECTED TO	1	167	3	93	6	1025	7	1225		
STRIP 3 CONNECTED TO	2	93	4	127	6	1031	7	1179		
STRIP 4 CONNECTED TO	3	127	5	24	6	882	7	910		
STRIP 5 CONNECTED TO	4	24	6	9	7	12				
STRIP 6 CONNECTED TO	1	1228	2	1025	3	1031	4	882	5	9
STRIP 7 CONNECTED TO	1	1678	2	1225	3	1179	4	910	5	12

table 3: connection of strips by tie points

Within the flight strips the images are connected to the neighbored images in the mean by 400 points, but also to the over next images by approximately 25 points. The tie of the different strips can be seen in table 3 (result of program PHOCON. program system BLUH). For example the flight strip 1 is connected to flight strip 2 by 167 points, to strip 6 with 1228 points. There is a very good connection to the crossing flight strips 7 and 8. This demonstrates the very stable geometry of the block.

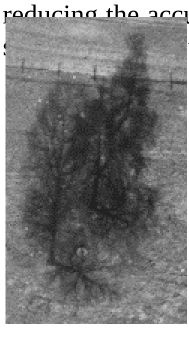
The bundle block adjustment with program BLUH has not caused any problem. The number of blunders was limited and could be respected by an automatic procedure. As standard deviation of unit weight (accuracy of image coordinates) +/-9.8µm have been achieved, a usual figure for the automatic aerotriangulation with large scale images. Because of the high number of points, the result can be manipulated. If the number of ground points is reduced from 49 324 to 47 419, the sigma0 value is reduced to +/-8.3µm and the connection of the images is still guaranteed. But such a reduction to only the observations with smaller corrections is not serious and has nothing to do with a correct blunder detection, it only looks better.

The accuracy of this block cannot be checked by the control points, they have been digitized from maps 1 : 5000 and do have a larger standard deviation than the sigma0 multiplied with the scale number. But there are some indications for a systematic block deformation. A detailed view to the selected points shows a high number of points located at the edges of shadows. This is not a problem within a flight strip, the time interval from one image to the next is in the case of an image scale 1 : 12 000 in the range of 16 seconds. But from one flight strip to the next it took approximately 10 minutes. The block is covering a city area with a usual height of the buildings in the range of 10m. The photo flight was in the spring at a sun elevation of 30°, causing 17m length of the shadows. Within 10 min the shadows are moving 75cm, much more than the internal accuracy of the block (9.8µm x 12 000 = 12cm). Especially the crossing flight strips with a larger time interval against the other strips are effected by this. In general the edges of the shadows are good candidates for the automatic image matching, they do have a very good contrast. Also other programs based on different methods than MEPAS are effected by this. An interest operator like the Förstner operator will identify also such points as candidates for the matching. During a demonstration of another program for automatic aerotriangulation it happened that the correct points located not on shadows have been deleted because of the higher number of points located on shadows. Such an effect will not influence the sigma0 of the block adjustment because all points are shifted in a similar way, but it will have a strong influence to the absolute accuracy.

fig. 4: points identified by automatic aerotriangulation, block Kapellen, original image scale 1:3000, square = points located on shadows (16), circle = other points (15)

In the case of the block Donar with an image scale 1:5700 reference data from a manual measurement with an accuracy of SX=SY=+/-2cm and SZ=+/-3cm have been available. Also the not so high number of points located on shadows has reduced the quality. The sigma0 has reached approximately +/-10µm. Even the 1400 points per image have not caused a very high outer accuracy of the orientation parameters, so with the independent check measurements only SX=SY=+/-4.3cm and SZ=+/-8.7cm was reached. By theory such a block should not depend upon the individual observations, the high number of points should lead to very accurate exterior orientations, which is also shown by the small numbers of inner the accuracy of the orientations in the block adjustment.

In the case of the very large scale block Kapellen (figure 4), the situation was more extreme. A sigma0 of only +/-15.7µm and a ground accuracy of SX=+/-4.6cm, SY=+/-4.1cm and SZ=+/-8.8cm at independent check points based on manual measurements with an image accuracy of +/-5µm has been reached. With the image scale 1:3000, the quality should be in the range of +/-1.5cm in X and Y and +/-2.3cm for Z. With the traditional manual measurements at analytical plotters this will be reached. But also if the points located on shadows are excluded from the adjustment, the sigma0 is only reduced to +/-15.2µm and the check points are improved just by 10%. That means for such a very large image scale, there are also other problems. As it can be seen in figure 4, most of the not-shadow-points are located on roof corners. Such points should be neglected because by the nature of the photo emulsion and also the blurring effect of image digitization, the edge location is shifted from the bright side to the dark side. This effect is different for the participating images and it is not totally random because of the directed sun shine. This is reducing the accuracy of the automatic aerial triangulation especially for large s uild up area



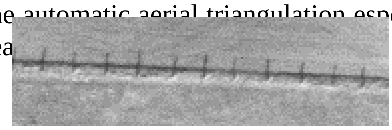


fig. 5: left: shadows in large scale images in rural areas - shadow of a tree (tree = small element in the lower part of left hand image), above: shadows of a fence

The mentioned problems are larger in build up areas, but as visible in figure 5, they are also present in rural areas.
The accuracy of the exterior orientation is only strongly depending upon the number and distribution of points in the photos if the photo coordinates are independent or not so much correlated. A correlation is caused by the representation of the objects, influenced by shadows and edge effects but also by the image geometry itself. With self-calibration by additional parameters only the major part of the systematic effects can be determined and respected. An analysis of remaining systematic image errors (Jacobsen 1984) showed strong local correlation's changing with the time interval between images. Another reason is the limited planeness of the camera magazine platens (Hakkarainen, Ruotsalainen 1978). By these reasons the improvement of the accuracy of the exterior orientation by a high number of image points is limited and the accuracy listed by the programs and also published by some authors is unrealistic.

CONCLUSION

Problems of the automatic aerotriangulation have been demonstrated. These are general problems present for all existing programs. The problems are larger for large scale images and in build up areas. Some unrealistic expectations in relation to the accuracy of the exterior orientation should be reduced. For a very precise determination of object points the manual or interactive method should be preferred. Nevertheless for most of the applications the fully automatic aerotriangulation is an economic solution, especially if the images have to be digitized by other reasons.

REFERENCES

Hakkarainen, J., Ruotsalainen, R. (1978): Checking the planeness of the magazine platens and camera frames of aerial cameras, The Photogrammetric Journal of Finland, 1978, No. 2, pp 101-110

Jacobsen, K.(19984): Analysis of remaining systematic image errors, Int. Archive Photogrammetry and Remote Sensing, Rio de Janeiro, Vol. XXV Part. A3a pp. 426-434

Wang, Y. (1994): Strukturenzuordnung zur automatischen Oberflächen-rekonstruktion, doctor thesis, University of Hannover

Wang, Y. (1996): Structural matching and its applications for photogrammetric automation, Int. Archive Photogrammetry and Remote Sensing, Vienna, Vol. XXXI Part. B3 pp. 918-923