APPLICATION OF SENSOR ORIENTATION DATA IN AERIAL TRIANGULATION

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INTRODUCTION

The modern photogrammetric technique for assigning coordinates to ground points, compilation and various derivations of topographic details, is highly accurate and efficient. However, its contribution towards the final goal - "the conversion of aerial photogrammetry to a self contained measuring method" - has been little (Blachut, 1964). The main reason can be attributed to inadequate insight into the realities of the operating environment of sensor orientation system, degree of precision of instruments and stochastic behaviour of observed quantities. Metric photographic camera is one of the geodetic sensors and elements of exterior orientation are camera position (XO,YO,ZO) and attitudes (WO,ØO,kO) at the instant of exposure in the object space. In this connection it is worthwhile to note the progress brought about by urgent needs in other field, mainly connected with navigation, space and ballistic projects and not by photogrammetric requirements. A review of today's state of the art in this field shows that all elements of exterior orientation of a sensor can be measured and recorded directly in various degrees of performance. The whole process is in state of rapid development. Consequently, a natural evolution of thinking raises the question - what is the utility of this data? How far the role of sensor orientation data may be complementary to photogrammetry if not competitive? The accuracy investigations presented here is thus based on the question:"if the camera station position in plan is introduced as observations, in which way would that influence the strip's and block's planimetric and vertical accuracy? Attitudes and height measurement of camera station have been excluded.

METHODOLOGY

The method used is a simulation technique, where random errors are introduced in image plate coordinates and camera stations position in plan (XO,YO). Real data from Oberschwaben test block is used for comparison. Since simplifications are necessary for generating the input data, selecting the parameters, etc. following limitations have been accepted:

- Investigations only deal with XO and YO as observations, having a known precision, assuming them to be correlation free.

- Simulated data is used to obtain the objective.

- For experiments with real data, only real image plate coordinate with rigorously computed position in plan for each camera station is used.

- For ground control configuration only full control location and number is varied. Chains of height control are provided at every 5 to 6 base length apart.

A computer simulation program is developed to generate and perturbate observations of image plate coordinates, sensor orientation parameters and ground control coordinates. Both the real and the simulated data are then subjected to bundle block adjustment program called GIANT (General Integrated Analytical Triangulation). This forms the basis for all adjustment algorithms. The relation between the inputs and the outputs are algorithms, as indicated in the schematic diagram in FIGURE 1.

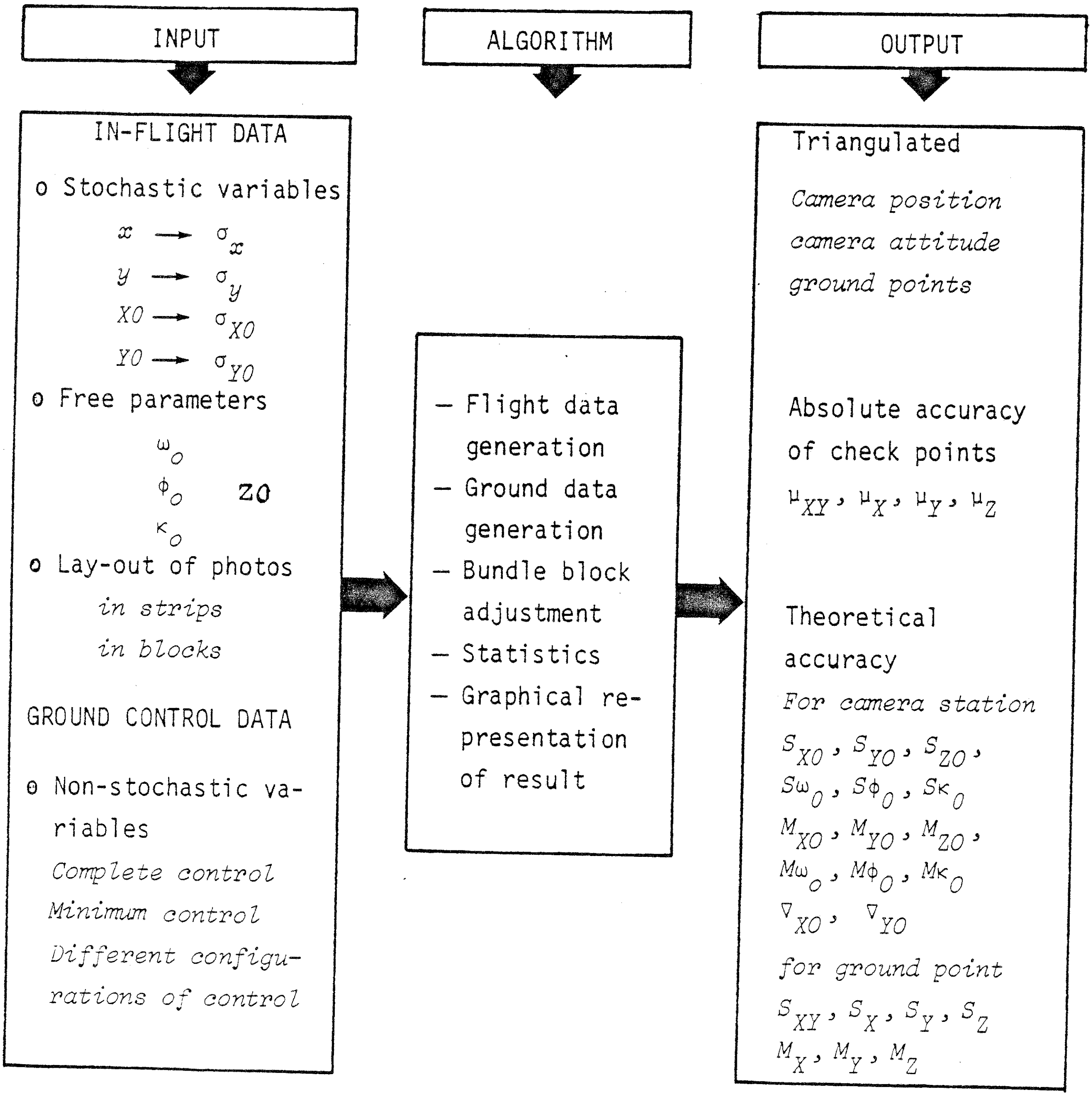

FIGURE 1. The relationship between input and output through process algorithm.

The implementation language for all programs is FORTRAN-IV and they are run on VAX-11/780 computer. The operative methodology thus consists in repeating the adjustment procedure with (as free parameter) and without (as constrained parameter) observations of XO and YO. As precision, values of 2m and 10m for XO,YO have been accepted based on a concise summary of various sensor orientation system performance given by Corten (Corten 1982 and 1983). Most of the known influencing factors of triangulation and adjustment procedure eg. strip length, block size, ground control configuration, photoscale, terrain type and side lap for simulated data are fuly considered. However for real data ground control configuration in strips and block size variation could only be considered due to constraints imposed by available data from oberschwaben tesh block. The ground coordinates of control points are treated as error free.

The accuracy investigations presented here are based on properties concerning "precision" and concerning "internal reliability". "Precision" includes absolute accuracy and theoretical accuracy. The results of the theoretical accuracy investigations are basically obtained as variance-covariance martix of adjusted ground coordinates, camera station position and attitude. This yields standard deviations as mean and maximum value for each adjusted ground coordinate and camera station parameter. While, for ground points, absolute accuracy at check points as well as theoretical accuracy are derived, only theoretical accuracy for camera station parameters are derived. "Internal reliability" studies in case of camera station position in plan are made. The outcome of the various experiments with simulated data is presented in selected graphs to emphasize only important results. Graphs for outcome of experiments with real data is not presented because trend remains the same as in case of experiments with simulated data.

DISCUSSION OF THE RESULTS

Investigations here are mainly concerned with schematised strips and square shaped blocks, as properties of rectangular blocks can be deduced from what we know already about square shaped blocks. Strips are treated separately in view of their application to linearly extended objects such as highways, coastal areas etc. Usability of introducing camera station position in plan as observations in adjustment procedure is discussed by comparing the results obtained with various cases and presented graphically because it yields realistic comparative deductions. Graphs are presented for absolute accuracy in plan, for each group of experiments as other statistics e.g. mean and maximum standard deviation remain fairly constant with respect to μ_{XY}. The graphs are presented in absolute units of "metres on the ground" to make them practically applicable. In theory and practice the dependency of the obtainable accuracies on various influencing factors - except XO,YO as observation with various precision are known fairly well. All results obtained here with case O - i.e., adjustment without camera station position in plan as observations - compare favourably with corresponding results as given by several investigators in past (e.g., Ackermann, 1966; Ebner, 1972). Although some study is related to IMT, the corresponding results are transferable to the present case at least qualita -

-tively. Case 2 and Case 10 means that the adjustment is done with XO,YO as observations with 2m and 10m precision respectively. FIGURES 2 through 6 demonstrate that: the RMSE increase with strip length and increasing length of control interval respectively; block adjustments with perimeter control give homogeneous results with smaller dispersion of standard deviation; the accuracy depends on the scale of photography, 60% sidelap is an effective means of increasing the accuracy without increasing the number of control points; terrain type variation has no significant influence on the final results.

Seeing the FIGURES 2 through 6, consistency of the graph shows that in all cases adjustment with case 2 is substantially superior than adjustment with case O; adjustment with case 10 is in general significantly closer to adjustment with case O. Therefore, further discussions mainly involve the results obtained with case 2. The following deductions concerning the simulated data can be drawn from various graphs shown:

- Strips with only 4 control points in the corner and with a fixed chain of height control located at five base lengths distance have been known to have very unfavourable planimetric accuracy properties, especially for strips containing more than 10 photographs. However, adjustment results for a strip with 30 photographs in case 2 can be made equivalent to those obtained by case O with only 14 photographs in a strip (see FIGURE 2). In fact, the dispersion in μXY in case 2, is so small that it suggests adjustment for larger number of photograph with same control. Thus, it is of particular interest to pursue some of such consequences further.

- It is seen from graphs in FIGURE 3 that in a square block consisting of five strips or more, the improvement gained in case 2 as compared with case O, is very slow (about 20% for 8 strips). But the trend is very pleasantly surprising and the value of μXY for case 2 gets stabilized with increasing number of strips in a squared shaped block.

- In FIGURE 4 it is seen that in case 2 the RMSE in strips having full control beyond 13 baselength not only remains within 15%, whereas in case O RMSE increases by a factor 2.5 for control at 30 baselength but, on the other hand, it shows the welcome possibility of stabilizing the accuracy of strip. Thus, it provides some vital information for planning purposes. The most remarkable gain in accuracy is obtained for cantilever strip as RMSE has improved by a factor of 90 and 37 for case 2 and case 10 respectively when compared with case O in a separate experiment. This is not shown here in graph.

- There has not been any spectacular gain in accuracy in case 2 as compared with caseO, for block adjustment with dense perimeter control, with relaxed and with minimum perimeter control. However, the trend has remained generally the same as was shown in FIGURE 2 through 4; and to this extent outcome of the experiments is encouraging.

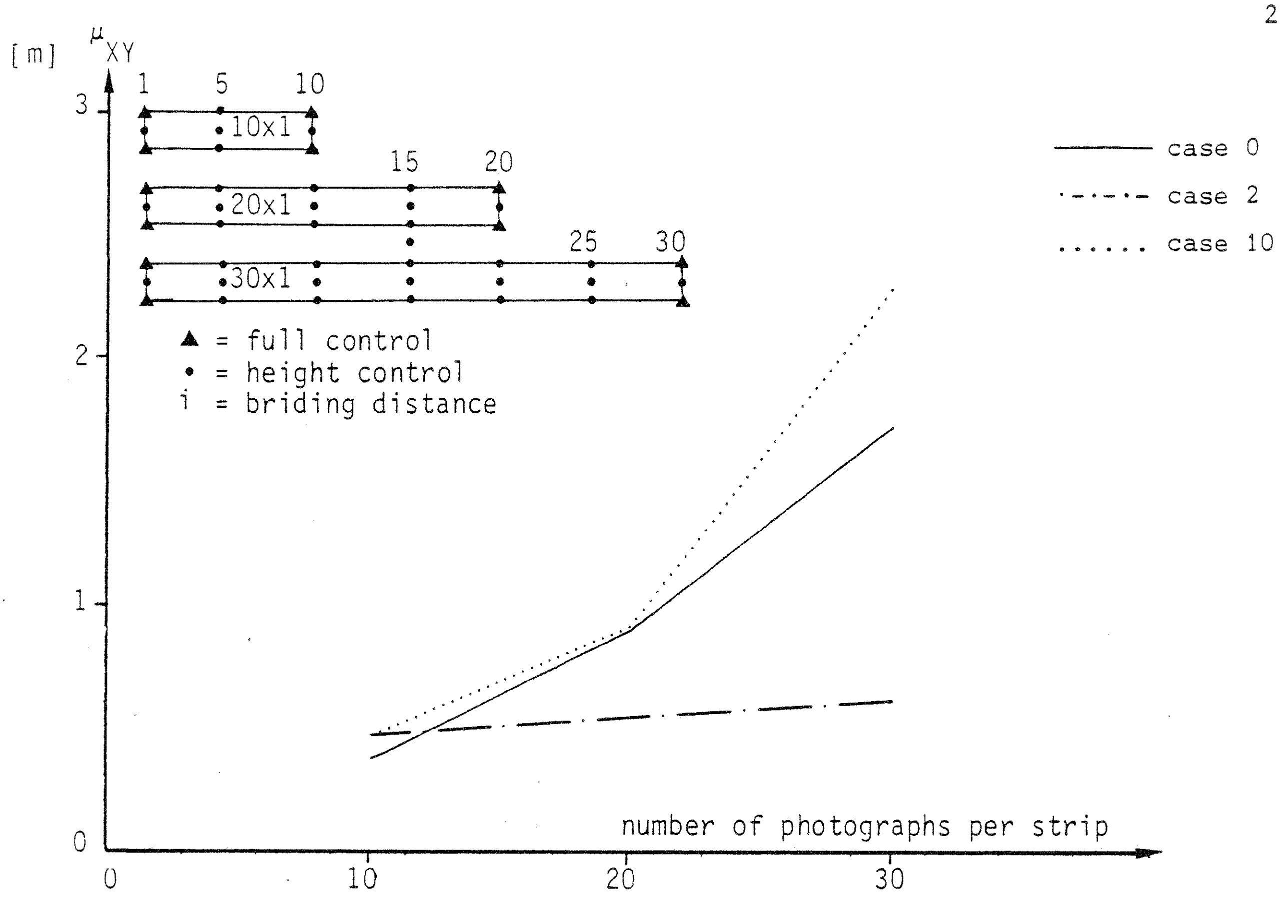

FIGURE 2 The relationship between RMSE (μ_{XY}) and strip length with four control points in the corners.

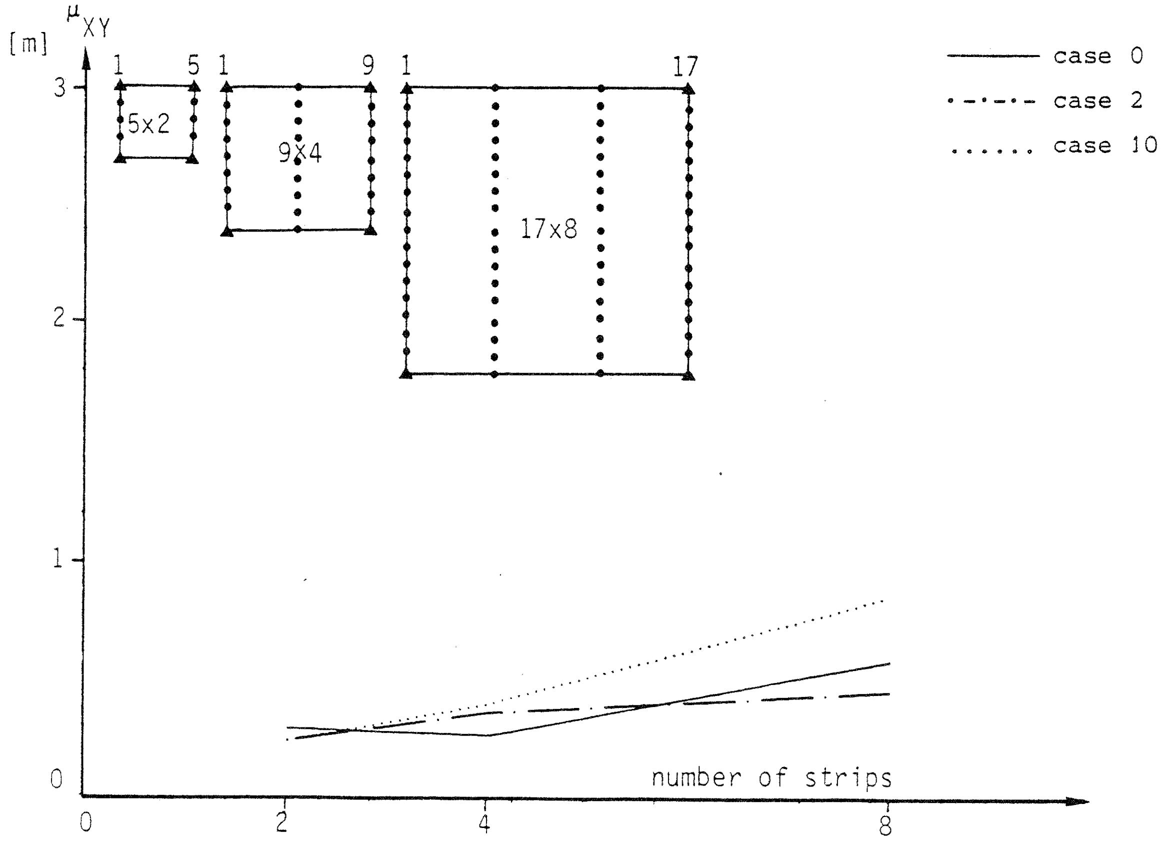

FIGURE 3 The relationship between RMSE (μ_{XY}) and block size with four control points in the corners.

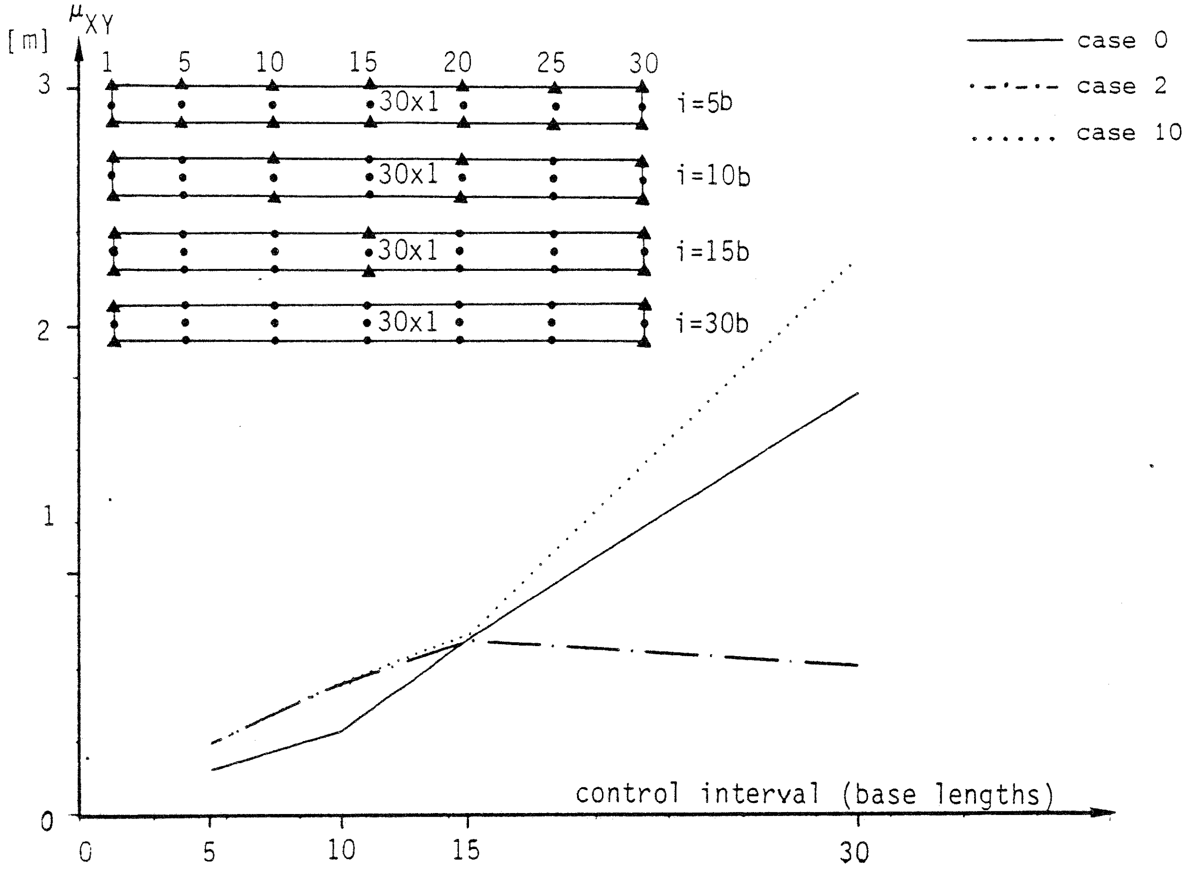

FIGURE 4 The relationship between RMSE (μ_{XY}) and control interval, in strips of the same length.

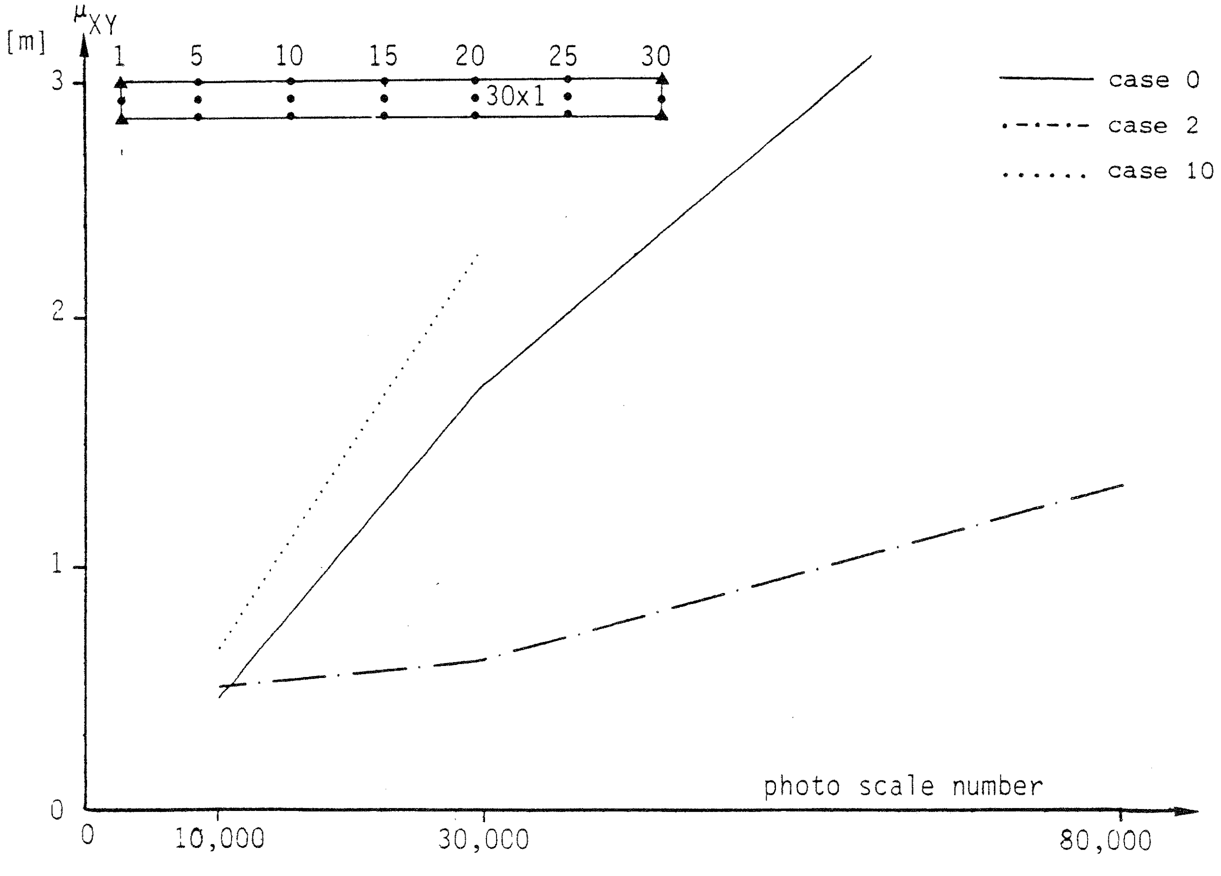

FIGURE 5 The relationship between RMSE (μ_{XY}) and photo scale in a strip with four control points in the corners

- Although - for a given strip length - the RMSE at check-points are linearly related to photoscale (see FIGURE 5) the loss in accuracy in case 2 for the corresponding case of photoscale 1:80,000 is much smaller (about 30%) than the loss of accuracy in case 0. An equivalent case becomes evident for photoscale 1:24,000 with case 0 and/or photoscale 1:80,000 with respect to RMSE.

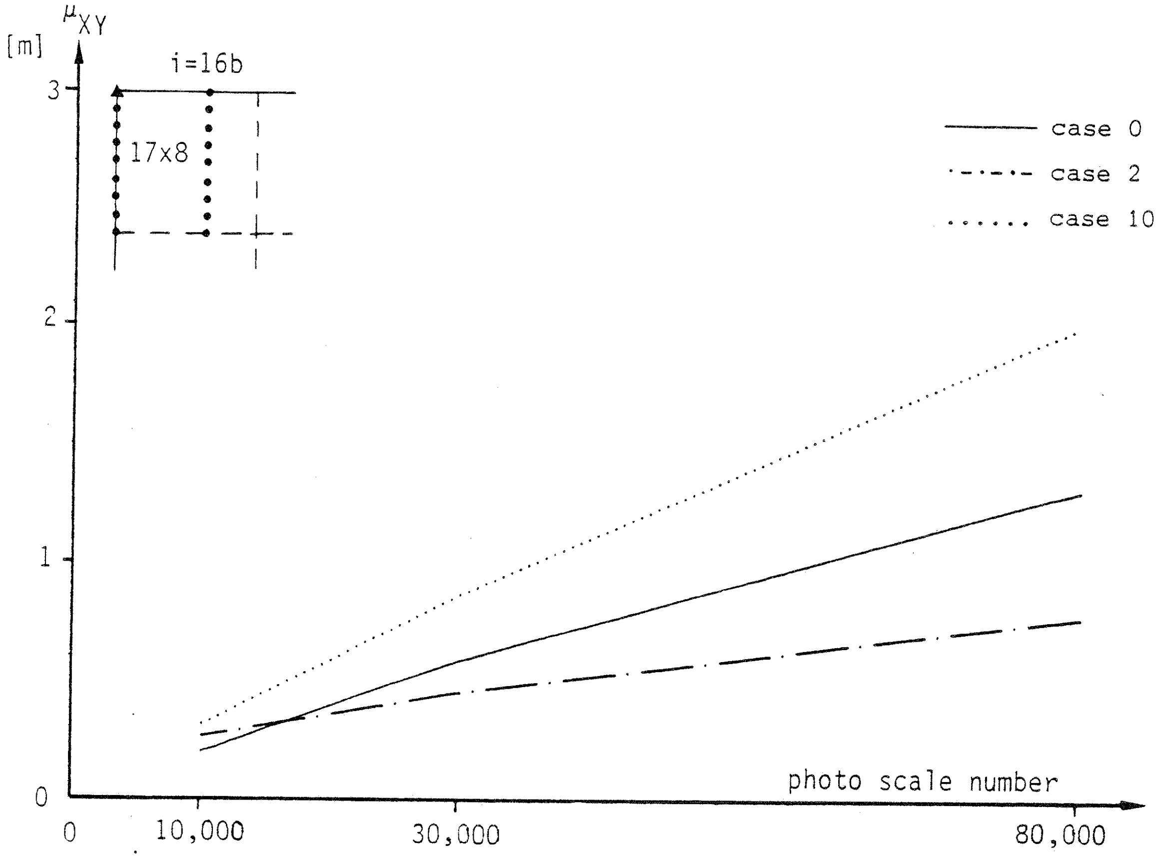

FIGURE 6 The relationship between RMSE (μ_{XY}) and photo scale in a block with four control points in corner

- With regard to the influence of photoscale on block adjustment with only four control located in corners when camera station position in plan can be used as observations (see FIGURE 6), trends remain the same as in case of strip adjustment. Comparing the RMSE at check points for photo scale 1:42,000 for case 0, and photoscale 1:80,000 for case 2, it is obvious that the use of camera orientation data is lucrative from economical point of view.

- Some investigations regarding precision of height have been done. Although, height control points are provided in chains as conventionally required in all the tests, certain aspects of the outcome is worth mentioning. There is a tendency to get improved height precision for case 2 as compared with case 0 and case 10. While theoretical precision has remained quite stabilized, root mean square error has considerably varied within each group of tests. Perhaps this is due to the number of check points used. Further investigation before coming to any positive conclusion is needed.

However, the results confirm that the accuracy in elevation is also weakly correlated with the planimetric accuracy (Talts, 1968).

- The investigations regarding internal reliability of camera station position in plan show a rather uniform value. This is primarily due to the fact that the camera station position's structure has a very regular pattern. Since reliability of a photogrammetric system defines its quality with respect to gross error detction and location, further investigations are required regarding mutual influence, if any, between the internal reliability of the camera station position in plan - as determined here - and those of photogrammetrically determined points e.g., (Forstner, 1980 Grun, 1980).

- The accuracy of all six elements of exterior orientation for all photographs (fictitious) in a strip or block - in terms of their mean standard deviation is also analysed. It is seen that values of mean standard deviation for position remains within small range of variation in each group of tests (30%) for case 2, whereas for case 0 and case 10 it varies upto a factor of 3 for photoscale 1:30,000. Large variations are noticed for the smaller scale 1:80,000 as could be expected. Variations in attitude, however, remain smaller. All mean standard deviations improve quickly as the number of the ground control point is increased in strip or block. The additional photographs improve the accuracy of the elements of exterior orientation for the photographs lying in the interior to a significant degree.

- The outcome of experiments with real data tends to confirm the results obtained with experiments using fictitious data. However, the relatively small number of results with short length of strip and block size, using the real Oberschwaben data and derived camera station position in plan, does not fully justify the establishment of comparative deduction, with respect to fictitious data. In fact, there is a great need for intensive research using real data, taking into consideration real data precision and related aspects of logistics.

CONCLUDING REMARKS

The following conclusions are based on the results of this study which is limited in scope by the nature of data and therefore should be adjudged preliminary:

- Eventhough the computational effort is more demanding with the GIANT program approach of utilizing camera station position in plan as observation, the adjustment results are more reliable because all the observational information is used simultaneously. Furthermore, lack of proven computer program can not be blamed for limited (or non-existing) use of sensor orientation data in aerial traingulation.

- Fundamental for the accuracy which can be expected is the quality of the XO,YO coordinates of the camera station measured at the instant of exposure. Consistency of the statistical result confirms the usability of XO,YO as observations, under the condition that it is obtained with a precision in the order of 2 metres. It displays a rather homogeneous accuracy and it remains pleasingly small even in the worst cases of cantilever strip, of long strips and of large blocks, controlled only at the corners with adequate chain of height control. A precision of the order of 10 metres for XO,YO does not contribute materially, except in case of cantilever strip.

- These results as mentioned above, suggest that it may be useful to reconsider the planning of photogrammetric projects with known conventional adjustments, i.e., to investigate the following question: with how many photographs a given area should be covered in order to yield optimum accuracy in case camera station position in plan (with known precision) can be incorporated in the adjustment procedure? Considerable saving in ground control can also be realized. In addition to this, equivalent accuracy can be obtained with smaller scales of photography (a factor of even 3 to 8) The use of sensor orientation data can make the photogrammetric method at all possible in cases where cantilever strip can find application. This also applies to cases where project area are poorly controlled and/or nearly inaccéssible.

- Whenever the geodetic method is substituted by the photogrammetric method, it is basically a question of possibility economy and time available for the determination of ground control points. It is evident from the present study, a considerable saving in production costs can be realized only if the job is done by analytical method utilizing camera station position data in plan when these are available at a precision in the order of 2 metres. In view of this, costs of developing systems to measure sensor orientation data (or to adapt existing navigation systems for photogrammetric sensor oritntation recording use) - be it only in plan position or both in plan and in height, or in attitude - might be well justified.

- The adjustment results obtained gives an indication about two important aspects. First, what should be the order of magnitude of performance of sensor orientation data in order to make it really useful for photogrammetric application and second, for what kind of ground data in aerial triangulation adjustment procedure may be useful.

- Finally, it may be suggested to manufacturers to develop instruments to record sensor oritntation data during flight at the instant of exposure, on the latest state of technology and without withholding any of the possible gains for any spefific purpose of user community. Because, science and art of photogrammetry stands to gain a lot by exploiting modern physical potentials of navigation methods, as there is no other known method to reduce the demand of ground control points in a similarly effictive and economical way.

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