

## REAL TIME ORIENTATION AS INTEGRAL PART OF ONLINE ANALYTICAL AERIAL TRIANGULATION\*

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### ABSTRACT

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For analytical stereoplotters, orientation of stereopairs is the fundamental process in aerial triangulation, and therefore an integral part of it. Hence, in a user-oriented environment, orientation and bridging should be solved as rigorously, automatically, logically and naturally as possible. This means, e.g.: no distinction between relative and absolute orientation, avoidance of point identification entries, simple distinction between different types of points, automated positioning according to available information, easy switching between plotter and comparator mode. In order to achieve these specifications, adequate statistical a priori information must be introduced, and an optimal solution be provided for the orientation parameters in real time. The paper is an attempt to specify such a solution by means of a structured program of the real time orientation loop. Preliminary results based on APL (see, e.g., Dorrer, 1979) simulations seem to justify the relevance of the approach.

### INTRODUCTION

The increasing relevance of analytical stereoplotters as well as computer-assisted analog stereoplotters has resulted in a certain rethinking of the process of aerial triangulation. Particularly in view of the detection of gross errors at an early stage, analytical instruments may be considered ideal mensuration and data-acquisition systems. In order fully to exploit the system's potential, the process of triangulation must be made truly online. This entails an optimal recursive solution, including the entire orientation procedure. Orientation may be incorporated in the triangulation process by means of a highly interactive orientation updating online or even real-time routine, callable at any instant of time. If the mathematical model is extended to comprise all types of triangulation points, no distinction between relative and absolute orientation is necessary. Based upon a unified approach, the paper attempts

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to describe and specify a general orientation routine for analytical stereoplotters. The findings can be applied to multiple stations.

#### BRIDGING ORIENTATION

Aerial triangulation is nothing but a multiple-station orientation. Hence, exterior orientation — relative and absolute — may essentially be understood as the fundamental process in strip and block triangulation. For any type of stereoplotter the basic unit, therefore, is the double image comprising two overlapping single images and defining an associated stereomodel. The classical determination of exterior orientation for analog instruments is generally a tedious task contributing virtually nothing to production: analog orientation, therefore, is a nuisance. If stereocompilation is performed in an analytical instrument, the process of exterior orientation has even become entirely irrelevant. The reason is that, as long as the orientation data of a stereopair are known, i.e. stored and readily accessible to the real-time computer of the analytical instrument, the stereomodel can be compiled at any time immediately after the restoration of interior orientation. Inevitable random observational errors on the fiducials are suppressed below negligible threshold values by a proper transformation (Kratky, 1972). Geodetic or photogrammetric pass points in the two images are not required at all in this stage.

In the purely analytical context, orientation therefore becomes entirely restricted to the domain of triangulation. Here, it has to be incorporated in the general triangulation process in a logical, simple, natural, user- and human-oriented interactive and automatic way. The orientation of a stereopair, therefore, must be considered an integral part of aerial triangulation with an analytical stereoplotter.

It seems highly unnecessary to distinguish between relative and absolute orientation from an organizational view point. The only useful separation stems from the possibility to consider geometric conditions, therefore to test the reliability of sections of the triangulation network. A purely online concept of aerial triangulation must give the human operator a series of obvious advantages in order to relieve him from any kind of tedious tasks. His main task must remain the precise measurement of points in the stereomodel, and the system must guide him in the most convenient and safe way. As an example, entries of point identification numbers must be avoided to the utmost, perhaps even entirely. Also, the automated positioning capability must be utilized to its extreme to the sole benefit of the operator.

#### COMPUTER-CONTROLLED POSITIONING

The operator should have the opportunity of continuously being able to decide, by simple means, on the accuracy state of the current model. This entails a mathematical approach geared towards a recursive or sequential solution (Mikhail, 1973; Dorrer, 1978). A properly designed real-time pro-

gram should permit the human operator to update the orientation of the current stereoimage at any time and at any position. The whole mensuration process can be substantially accelerated by the automatic positioning capability, if adequate functional and statistical a priori information is utilized. The better this information, the better the positioning, i.e., the less is the amount of necessary manual course settings in the stereomodel. Particularly important is that all types of triangulation points for connecting adjacent images, be distinguished from each other in order to initiate different actions.

Fig. 1 shows part of an automated positioning routine ("AUTO") that would perform such a task. "AUTO" will be activated as long as the system has sufficient information about image points to be positioned. The information must be collected from available control data and from previous measurements, and prepared for a logical serial processing. Four triangulation point types must be distinguished, viz.

- *old tie points* to previously measured stereomodels, and for which the image coordinates in the primary image are known,
- *old control points* having been measured in the previous stereomodel, i.e. the image coordinates in the primary image are known,
- *new control points* i.e. control points not having been measured previously,
- *new tie points* for connecting the current model to the next model.

"Old tie points" (OTP's) and "old control points" (OCP's) can be exactly positioned by computer control in the primary image, i.e., the image common to the previous model. While OTP's in the primary image should be locked after positioning, the fine measurement of OCP's must still be left to the human operator. Positioning in the secondary image, i.e. the new image, is only approximate, since both the orientation of the secondary image and the object location of OTP's are not known exactly. It is essential, at this stage, to make extensive use of a-priori statistical information on the secondary orientation and on the object (e.g. by interpolation). Only a recursive solution can give — step by step — optimal results for positioning sufficiently close to the desired image points. "New control points" (NCP's) can be positioned only approximately in either image, "new tie points" (NTP's) may be positioned exactly in one image according to a predefined point pattern, while in the other image only approximately.

During computer-controlled positioning of image carriages, the need arises as to whether a given object point, i.e. either control or interpolated tie, actually lies within the region covered by the current stereoimage. Theoretically the exterior orientation of each of the two images has to be known and utilized. In other words, each object point has to be mathematically projected onto each of the two image planes, and then be tested for falling inside or outside a pre-specified image format. This procedure may be denoted "windowing the object". It is obvious that the degree of convergence in positioning will be directly dependent mainly on the accuracy of exterior orientation. No point identification numbers, though, need be entered or specified in this way.

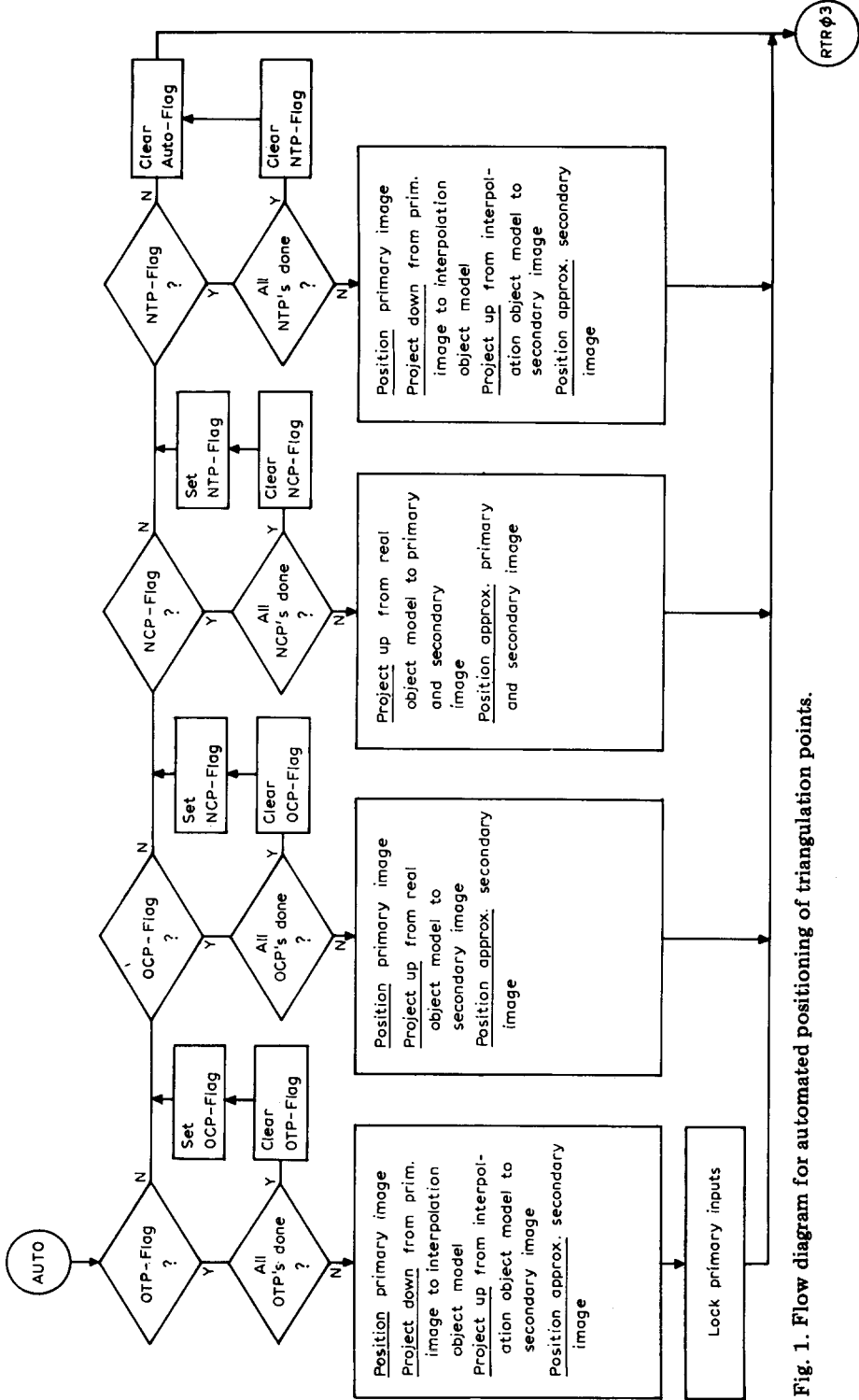


Fig. 1. Flow diagram for automated positioning of triangulation points.

Any automatic positioning of a point pair must be followed by a real time routine in order to allow the human operator to manually perform coarse and fine settings to the exact point location, as well as to permit sufficient time for making decisions only the human can make. Such decisions are, e.g.: should the current point be used for updating the orientation or should it just be recorded. The real-time program (Fig. 2) must perfectly complement the computer-controlled positioning routine. An extremely useful feature is a programmed foot switch, called parallax switch, that interrupts the normal (primary) real-time loop, giving control to a secondary real time loop. Upon activating this switch, the operator would only gain control to the secondary image, thus observing parallaxes. Whether distinction between these two loops is made mostly by hardware (Jaksic, 1978) or software, is immaterial. The parallax switch may additionally be designed as discriminator between observed points to be recorded only or to be used for updating the current orientation. The two real-time loops must safeguard against improper activation of switches (see Fig. 2). Thus, orientation updating ("ORIUP") is only possible if the parallax switch is depressed in "AUTO" mode or in manual "CONTROL" or "TIE" mode. From a practical view point, provision must be made for rejecting ("REJECT") the previously updated orientation by a "downdating" procedure. Also, a previously downdated orientation must be recoverable ("RECALL").

At the current stage of technology it seems feasible to optimize computer-controlled positioning only along strips. However, if digital point transfer would be carried to its extremes, and the mensuration process would follow patterns different from the conventional strip/strip-structure, entire blocks could be processed in a similar manner. The theory behind such speculative statements is based on the block adjustment approach investigated by Albertz et al. (1974).

#### UNIFIED APPROACH

Essential property of the mathematical model for such an orientation updating program is that, in order to optimally accommodate these four point types, a unique set of condition equations must be used. Since the coplanarity condition inherently contains no information on the imaged object (e.g. object coordinates of control points do not occur), its use is limited. Only the collinearity condition is applicable to a truly unified approach to a general external orientation. Its theoretical incapability to comply with stereoscopic measurements can be overcome by modifying the statistical model, viz. to include cross-correlated image coordinates. This means that the covariance matrix for the four stereoimage coordinates is not a diagonal matrix if parallax was cleared stereoscopically. In fact only differences were measured independently, yielding correlated image coordinates.

All point types are then treated alike and by the same mathematical formulation. Following Brown (1971), the stochastic model is extended further to

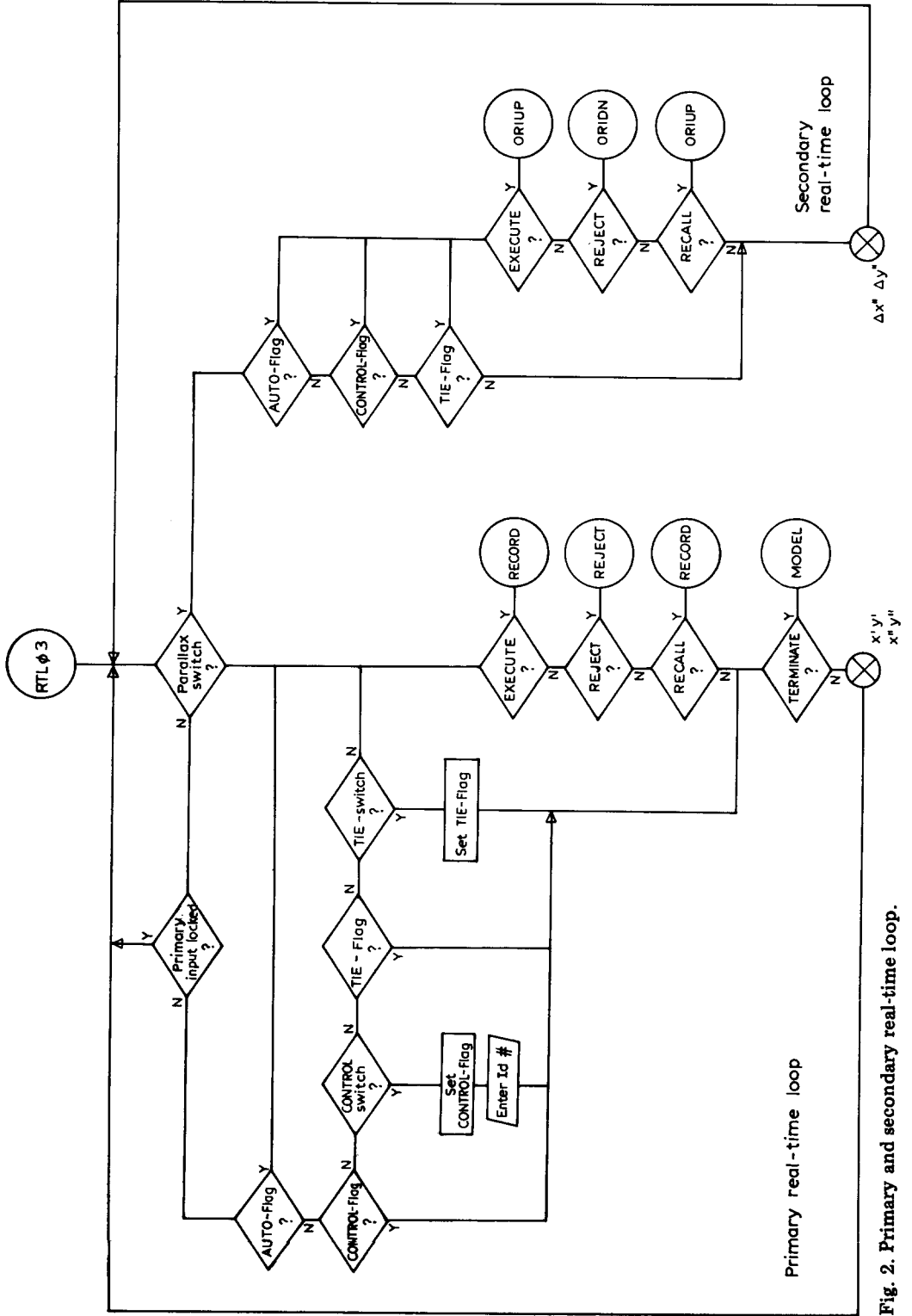


Fig. 2. Primary and secondary real-time loop.

accommodate different kinds of control by using statistical a-priori information for the object coordinates. If this approach is extended to include all other point types as well, a unified optimal solution can be expected. The following table exhibits the trace of the covariance matrix for image ( $K_x'$ ) and object coordinates ( $K_x$ ) for the four triangulation point types.

Point type	$\text{tr}(K_x')$	$\text{tr}(K_x)$
OTP	0	$< \infty$
OCP	0	$< \infty$
NCP	$> 0$	$< \infty$
NTP	$> 0$	$\rightarrow \infty$

It is essential that statistical a-priori information be introduced as realistically as possible. E.g. the object position of a new tie point lying within a certain image may easily be estimated with an accuracy of several hundred meters.

Unfortunately, this approach does not work from the very beginning of the data collection scheme. As long as only insufficient information has been gathered, the system underlying the mathematical model is singular, and a unique optimal solution cannot be reached. E.g., if sufficient control is lacking, the system will be underdetermined and will carry on its rank defect for a considerable bridging distance. This problem is particularly serious for longer sections without control. Theoretically the only way out of this dilemma is to consider orientation parameters as random variables and, by introducing proper statistical a-priori data, to perform a truly conditional adjustment, or in modern terms of estimation theory, to process the data through an optimal (recursive) filter. This approach imposes no difficulties for a single stereopair, but results in a substantial increase in the number of equations if more stations are involved. Ultimately, however, this kind of approach will be chosen, particularly when fast real-time computers with floating-point and array processors will be readily available.

If the orientation parameters are treated as genuine unknowns, the mathematical model takes the form of a combined adjustment. Though more pleasing from a conventional photogrammetric view point, this approach is stochastically unrealistic, for the inherent infinite variances are definitely wrong. Practical tests have shown that, as theory would predict, a somewhat better fit is achieved with the filter approach. However, aerial triangulation being only concerned about the optimal fit of coordinates, the combined adjustment approach seems feasible. The problem of rank defect for the underdetermined case can be overcome by utilizing a minimum norm-generalized inverse solution. Simulation tests with APL indicate the feasibility of both approaches. However, considerable theoretical and practical research is still required until final adequate solutions can be expected.

## CONCLUSIONS

Orientation should be as general as possible for analytical stereoplotters, and it should be integrated into the triangulation process. The human operator must have the opportunity to optimally update the current orientation at any time and at any position. He must be able to reset the orientation to a previous stage by removing already used data. Distinction between different types of points must be made as simple as possible. Point-identification number entries should be avoided entirely. Adequate use of statistical a-priori information must be made. Simple and logical facilities must be provided for switching between plotter mode and comparator mode. Automated positioning according to available information must be as accurate as possible. This means that accurate orientation parameters be known at an as early stage as possible. Optimal recursive solutions are inevitable.

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