Instrumentation for Analytical Triangulation

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ABSTRACT: *Interest in the rapidly developing field of analytical triangulation has thus far been focused primarily on mathematical procedures and other theoretical studies. In this paper are introduced the operational aspects of a practical analytical triangulation system and the instrumentation requirements discussed. The current program at U. S. Army Research and Development Laboratories to develop and evaluate an effective analytical triangulation system for military use is described.*

INTEREST in analytical triangulation is growing rapidly. Data regarding its practical capabilities are still meager, yet it is believed in many quarters that this system of extending and adjusting ground control will occupy an important place in future mapping operations. Its greatest application is foreseen in military mapping where the need for aerotriangulation is perhaps the greatest, and where development using map plotting instruments for this purpose has apparently reached a stalemate.

Current interest in analytical triangulation has thus far been focused on the mathematical aspects. A great deal has already been accomplished in this respect. Tests using electronic computers have shown that a variety of old and new computational procedures are now operationally feasible and that the purely mathematical errors introduced through their use are limited to round-off errors of insignificant size. Some of the basic analytical approaches are now being extended to make them applicable for use in diverse control extension situations and to adapt them for use with airborne data such as APR, Shoran and with convergent photography.

With the course of action well chartered for the development of the computational procedures it is timely to consider the operational aspects and instrumentation requirements. Significantly, the key to successful analytical triangulation is held primarily by the series of simple, yet all important, operations involved in pass-point data gathering. Effective tools for accomplishing these steps are still to be developed.

All phases of analytical triangulation are currently being investigated at the U. S. Army Engineer Research and Development Laboratories. This paper is limited, however, to a discussion of the operational phases involved in analytical triangulation. The paper contains a review of procedural requirements, factors in optimum instrumentation, and an outline of the test and developmental program at USAERDL is given.

Before considering the main subject it will be advantageous to summarize the potential advantages of analytical triangulation. These must serve as the guide posts and goals in designing the most effective procedures and instrumentation.

POTENTIAL ADVANTAGES

The potential advantages of an analytical triangulation system are:

1. *Increased accuracy* over aerotriangulation techniques using map plotting instruments through:
   a. More precise compensation for systematic errors.
   b. Mathematical adjustment of random errors.
   c. Less reliance on operator skills: fewer accidental errors.
2. *More effective military utilization* through:
   a. Simple, lighter and less temperamental equipment.
   b. Less skilled operators.
   c. Speedier operations.
3. *Greater adaptability* for
   a. Use with convergent photography without attendant calibration problems.

b. Use with airborne orientation and position data.

The foregoing advantages can be realized only by effective solution of the challenges offered by the operational requirements that follow.

Operational Requirements

Analytical triangulation is analogous to the triangulation or bridging method using map plotting instruments. The essential difference, very briefly, is that in analytical triangulation the models are formulated by mathematical equations: an actual optical model is not used. Pass-points are selected and measured on the diapositive plates. In plotting instrument techniques an optical model is oriented and used to provide data.

The operations necessary to gather the pass-point data for use in analytical triangulation computations are:

1. *Selection of pass-points.* The same point must be chosen, generally on three consecutive overlapping photographs.
2. *Marking of pass-points* for immediate use and for later reference.
3. *Measurement of pass-points* with respect to the photographic axes.
4. *Correction of pass-points* for aerial camera lens distortion, for film shrinkage, and for other known systematic errors.

At the present time facilities designed expressly to accomplish the foregoing operations are non-existent. A few *general requirements and observations* regarding each of these deceptively simple operations is next given.

1. *Selection.*—The stereocomparator, the conventional approach to the selection and measuring operations is objectionable from a military standpoint when it approaches the size, complexity and cost of the heavy-base map plotting instruments. Precision screws, and complex optical trains introduce manufacturing, calibration, and maintenance problems that must be avoided. What is needed is simple, light, instrumentation of sufficient accuracy that will provide for analytical triangulation the effective tool provided for map compilation by the Kelsh Plotter.
2. *Marking.*—The main consideration is that the pass-point must be quickly and precisely marked on at least one but preferably on all three consecutive photographs. Numerous potential means are available: a photographic record, marking or etching using dyes, or ultra-violet light, and mechanical means.
3. *Measurement.*—Measurement of the pass-point coordinates should be reliable to within 5 microns. Besides precise lead screws the design possibilities under consideration incorporate glass-scales, glass grids, and systems based on the interferometer principle. A solution that readily lends itself to automatic read-out is preferable.
4. *Corrections.*—All of the potential systematic errors caused by lens distortion and dimensional changes in the aerial film can be readily eliminated by correcting the pass-point coordinates. The required computations can be programmed for solution together with the triangulation computations in the electronic computer. The problem is in establishing the corrections to be made. To obtain more reliable data, aerial camera calibration of higher accuracy is now demanded together with more data concerning the differential shrinkage errors in each photograph.

The foregoing operations provide the data that is supplied to the electronic computer which then solves for the ground position and elevation of the desired pass-points. A wide variety of general purpose computers are available to meet the storage and speed requirements imposed by the analytical computations. A discussion of the comparative merits of these computers as well as consideration of special purpose computers is beyond the scope of this paper. In passing it might be noted that the rapid progress in computer design promises even greater applicability in the solution of the triangulation and other photogrammetric problems.

The preceding has been a rapid survey of some of the operational aspects involved in analytical triangulation. What follows is a brief description and highlights of the instrumentation in experimental use and instrumentation under development at U. S. Army Research and Development Laboratories. The tests have a two-fold purpose: first, to provide data from which estimates of the accuracy of analytical tri-

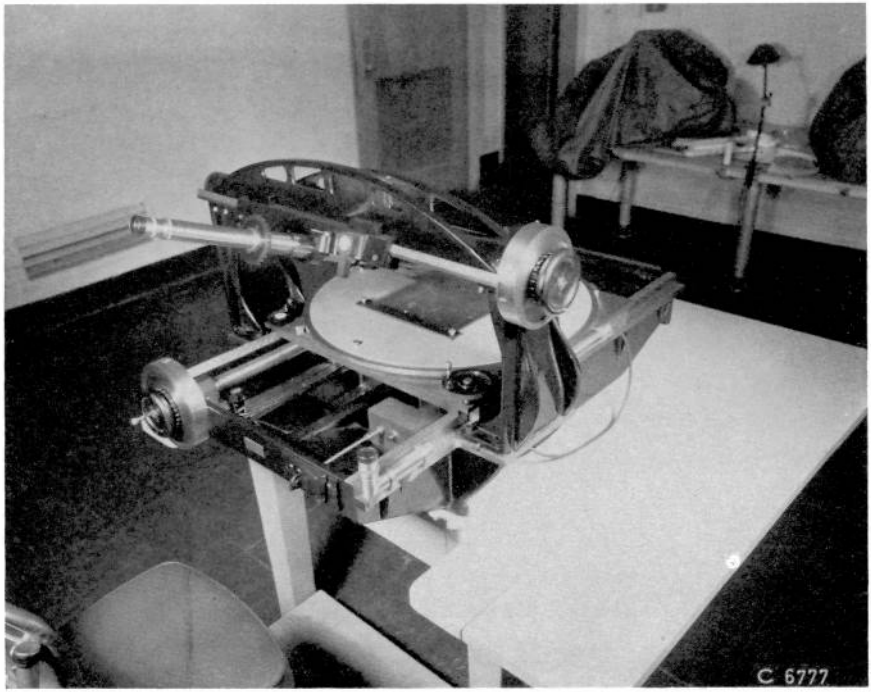

FIG. 1. Mann Precision Comparator.

angulation can be made and errors and their adjustment can be studied and, secondly, to evaluate existing equipment and to develop new equipment to conform to the requirements discussed in this paper. In the tests a number of photographic strips used previously in aerotriangulation tests using stereoplotting instruments are again being used to provide comparative accuracy data. Adequate ground control exists in the areas photographed so that various actual control extension and adjustment situations can be simulated.

COMPARATORS

Two comparators have been drafted for service to make the coordinate measurements necessary for current analytical triangulation tests. The first is the Mann Precision Comparator, Figure 1. In the laboratory type tests in which it is being used, the inherent limitations of monoscopic viewing are intentionally avoided. Only pass-points suitable for precise monoscopic identification at 15-time magnification have been selected. The tests are intended to capitalize on the high precision of the instrument. All computations including shrinkage and lens distortion corrections have been programmed for the IBM 650 electronic computer.

The main virtue of the second instrument, the Steinheil Stereocomparator, Figure 2, is its availability for providing immediate accuracy test data and for aid in evaluating the stereocomparator approach to instrumentation. This old German instrument, recently reconditioned by Photogrammetry, Inc., has a least reading of 0.01 mm., and is equipped with a mechanism for etching a 0.4 mm. circle about each selected pair of pass points.

RESEAU SYSTEM

An interesting approach to the instrumentation problem is incorporated in a reseau system developed, and being effectively used, by British Ordnance Survey. The same instrumentation scheme, but with a different analytical method, is currently being tested for USAERDL by U. S. Army Map Service. In the reseau system the aerial photography is exposed in a camera that is equipped with a one centimeter rectangular reseau etched on glass and placed at the focal plane of the

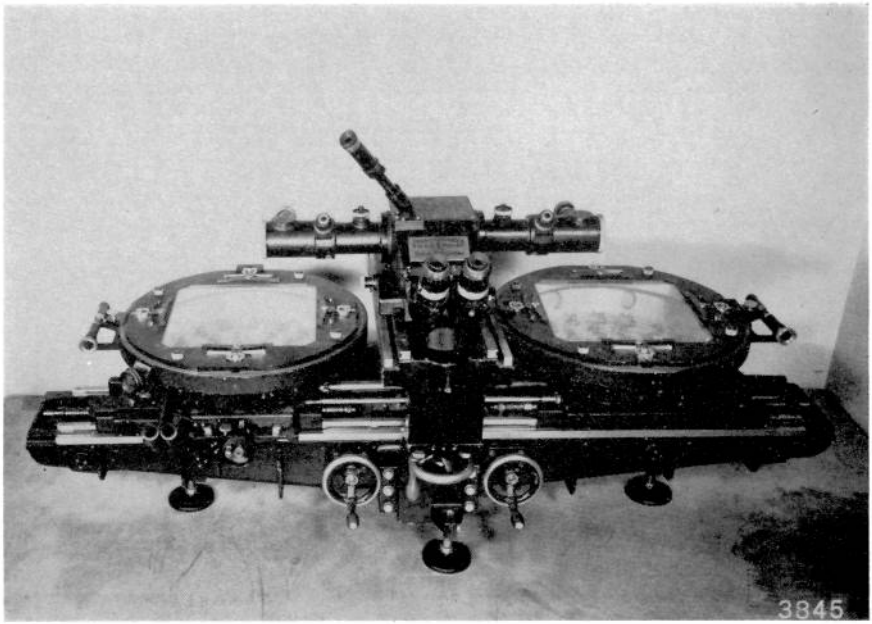

FIG. 2. Steinheil Stereocomparator.

camera. The calibrated reseau crosses that appear on each photograph are subsequently used as minor pass-points and as a reference grid to facilitate the measurement of regular pass-points.

The following unique advantages of the reseau system are to be investigated. It provides:

(a) Precise control over the differential as well as the uniform film shrinkages.
(b) A ready source of pass-points (reseau crosses), the coordinates of which are already known on one photograph.
(c) Potential simplification in coordinate measurement procedures and instrumentation.

The instrument being used in conjunction with this system is the Cambridge Stereocomparator Figure 3. It measures the x and y distance from the pass-point to the nearest reseau cross.

ZURLINDEN SYSTEM

A very promising instrumentation has been devised by Robert Zurlinden. The system utilizes three separate components: Pass-point Enlarging Camera, Selecting and Marking Instrument, and Measuring Instrument. These instruments are being fabricated under USAERDL contract by Photogrammetry, Inc., and Union Instrument Corp. The brief description of the procedures that follows indicates the function of each component.

The first step is to select and circle enough pass-point locations on prints of the photographic strip to satisfy the computational requirements. Precise identification is unnecessary since this is primarily a planning operation.

After this preliminary work the film is placed in the Pass-point Enlarging Camera where a 10-time enlargement of the area in the vicinity of each pass-point is made on $2\frac{1}{2}$ inch wide, roll enlarging paper. The design of the instrument restricts to a set number the coordinate positions in which the camera can be used. These precise locations are photographed from scales onto a small area reserved for this purpose on each pass-point enlargement. A 2-inch by 2-inch enlargement also collects on one photograph the areas in the immediate vicinity of each of the four fiducial marks on each negative. The position of the fiducial marks on the enlargement is later compared with a calibrated chart to indicate the shrinkages of the negative.

The pass-points are next selected by examination on three enlargements made

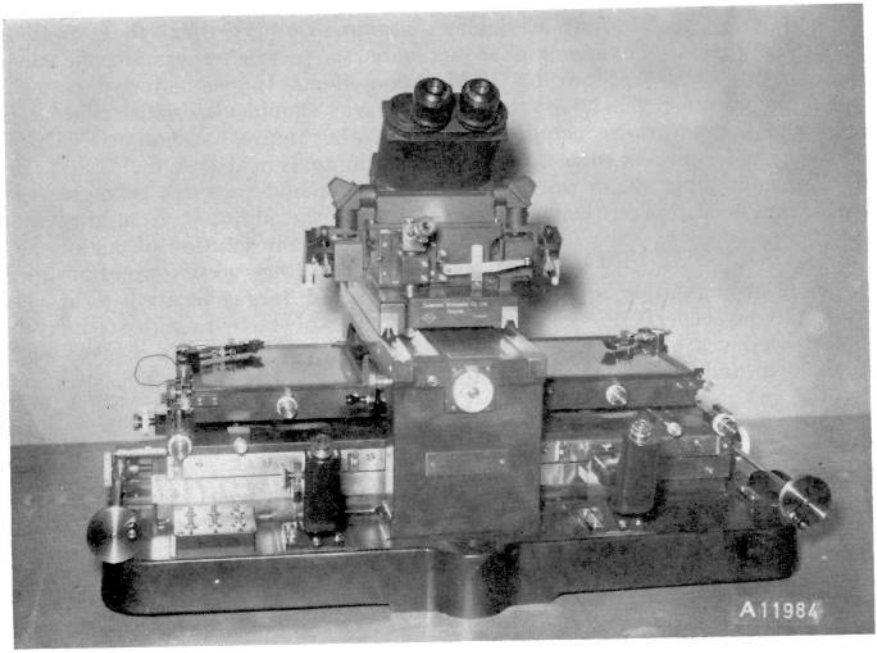

FIG. 3. Cambridge Stereocomparator.

from three consecutive aerial negatives. This procedure is carried out in the Selecting and Marking Instrument. This instrument provides direct viewing of the pass-point area as it appears on a stereoscopic pair composed of the first and second overlap, and on a pair composed of the second and third overlap. The two stereoscopic pairs appear on small adjacent mirrors so that ready comparison can be made to assure identification of the same point on the three photographs. After selection of the points they are marked by mechanical means.

After identification and marking, the corrected coordinates of the pass-points are obtained in the Measuring Instrument through two components: a measuring element and a correcting element. The measuring element determines the coordinates of the pass-points with respect to the center of the enlargement. The correcting element applies separate corrections to the measuring system for displacement caused by the film shrinkage, lens distortion, and other known systematic errors.

Potential advantages of Zurlinden's instrumentation are that it

(a) Consists of portable components with no precise lead screws, handwheels, or calibration problems.
(b) Provides for positive identification and location of pass-points on three consecutive aerial exposures.
(c) Accomplishes the entire data-gathering procedure with possibilities for speed-up of operations through the simultaneous work of several operators.

RECORDING STEREOCOMPARATOR

The expanding need for stereocomparators in the missile test, mapping, and laboratory testing fields is being met by a number of manufacturers through the development of large and versatile instruments. One such instrument, the Nistri Stereocomparator TA-3, has been ordered by USAERDL for early delivery. In this instrument glass diapositives of three consecutive exposures can be oriented at the same time. Through optical switches each of the three pairs in the triplet can be viewed alternately in rapid succession and comparison made of the potential pass-point as it appears on each pair. After it has been selected, the pass-point and floating mark can be photographed on 35 mm. film for future reference. Among numerous features that are provided to facilitate operations are: motor drives in the x and y directions, optical rotation of each plate,

and variable magnification for each ocular (to permit viewing of convergent photography). An automatic readout on IBM cards is planned by USAERDL so that all the necessary computations including the coordinate transformation, corrections, triangulation, and adjustments can be performed as one operation in the computer.

Future Instrumentation

Analytical triangulation offers at least two attractive prospects for the future. First, it introduces an effective tool for tracking down and destroying the photogrammetric gremlins that consistently sabotage most photogrammetric triangulation efforts. Ingenious instrumentation on the way should materialize this, as well as the other impressive potential advantages of the analytical system.

The second prospect is of greatest concern to the military. Analytical methods offer hope for solution of one of the most urgent military needs—rapid processing of maps and target location data. The remaining obstacle to automation, that of pass-point selection, is a great one, but surely not insurmountable.

Review of The Ottawa International Photogrammetric Conference on Aerial Triangulation

An International Conference on aerial triangulation was held at the Canadian National Research Council in Ottawa, Canada, during the period, August 28–31, 1957. The conference was jointly sponsored by the National Research Council and the Canadian Institute of Surveying.

The opinion of many of those attending was that the program, under the direction of Mr. T. J. Blachut of U. R. S. was very fine, and the hope was expressed that more such conferences would be possible in the future.

The evening hours and Saturday were taken up with an elaborate social program, typical of the Canadian Hospitality.

A complete account of the conference is to be published in a forthcoming special issue of "Photogrammetria." The following are abstracts of papers on subjects connected with aerial triangulation, that were presented at the conference by several well known photogrammetrists.

Abstracts of Papers

GENERAL CONSIDERATIONS ON ANALYTICAL AERIAL TRIANGULATION

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The ultimate accuracy of aerial triangulation will be limited by the combined effect of aircraft movement and refraction. Aircraft movement makes a short exposure time necessary. This prevents the elimination of the effect of random local refraction, which would be effected if a mean image position were obtained through time exposure. Since the size of the air masses involved is