51284

UNITED NATIONS
ECONOMIC AND SOCIAL COUNCIL

Distr.
LIMITED

E/CN.14/CART/193
12 August 1966

Original: ENGLISH

ECONOMIC COMMISSION FOR AFRICA
Second United Nations Regional
Cartographic Conference for Africa
Tunis (Tunisia) 12-24 September 1966
Provisional agenda item 12(b)

PHOTOGRAMMETRY FOR REGIONAL MAPPING

Submitted by the Government of the United States of America

M66-1115

PHOTOGRAMMETRY FOR REGIONAL MAPPING[1]

ABSTRACT

Three different systems are compared for mapping a large heretofore unmapped region. One system uses photography from an earth satellite, a second from an ultra-high aircraft using auxiliary data, and a third from a conventional high altitude aircraft with or without auxiliary equipment. In each system analytic aerotriangulation plays a key role.

Analytic aerotriangulation is a computational method by which all the photographs of an area, or block, are adjusted simultaneously to fit each other and to fit conventional geodetic control as well as all other auxiliary data (e.g., from a solar camera) which one may wish to impose. The output of the computation consists of the X, Y, Z space co-ordinates of several objects shown on each photograph; these points are regarded as control for later compilation with stereoscopic plotting instruments. The input data consist of the x, y co-ordinates of images on the photographs measured with a comparator.

The expected accuracy of each system is progressively poorer in the order named, the best being of the order of 2 to 5 metres. Nevertheless, the third or worst system may still have an attractive potential value because of its almost immediate availability. Its error may be as much as 120 metres, but the error could be transformed, and/or recomputed, at a later time when a dense net of adequate control is available. The results are expected to be amply accurate for a reconnaissance-type of planimetric map at 1:50,000 scale for resources inventories and regional planning.

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INTRODUCTION

This discussion is presented in conjunction with two others prepared for the same conference: Lansing G. Simmons, "Satellite Triangulation"; and William D. Harris, "Aerial Photography for Surveying and Mapping". Each paper offers suggestions for dealing with large unmapped areas, such as portions of Africa, or the entire continent. This particular paper describes analytic aerotriangulation and indicates how this technique may be advantageously employed.

Several assumptions are made in this discussion. Geodetic points can be established by means of satellite triangulation, but just when this will be accomplished is not clear; it seems logical to expect that the completion could be hastened significantly by a unified request from all the peoples of the region. In the meantime it may be necessary to apply certain interim techniques. Several different types of aerial photography are suggested in the paper of Mr. Harris; although these are considered to be entirely appropriate, a third type is discussed here in the interest of timeliness. Throughout all of these suggestions it is assumed that analytic aerial triangulation is the fastest, cheapest, most accurate and appropriate method for the efficient utilization of ground control.

It is also assumed that the region has urgent need of maps for the inventory of natural resources and for regional economic planning. A very important economic need would be served if such maps were available immediately; at least within a year or two. Consequently it seems appropriate that a map having a scale of 1:50,000 or smaller, and without contours, would fill many of the urgent needs, except for isolated small areas where engineering projects may be contemplated (Hotine, 1965; Schermerhorn, 1964, essays by Gamble, Koushin, and Wiggins; Zarzycki, 1963).

It is therefore suggested that 1:100,000 scale photography be obtained with colour film and also infrared if necessary, 60 per cent overlap in both directions, with a super-wide angle camera of about

9 cm focal length from an altitude of about 9000 m. This can be arranged and accomplished almost immediately, depending on seasonal weather and atmospheric conditions.

Analytic aerotriangulation and subsequent map compilation can be accomplished without auxiliary data, but every bit of such data adds accuracy to the system. Analytic aerotriangulation offers the possibility of incorporating almost any kind of auxiliary data and controlling the influence (weight) on the solution. Mr. Harris has mentioned the solar camera and the laser altimeter, which are ideal. Other items include SHIRAN, APR, horizon cameras, statoscope, etc., (Bush, 1964; Corten, 1964; Di Carlo, 1964; Jeri, 1966; Livingston, 1966; Zarzycki, 1964).

Obviously a dense distribution of geodetic control is required to produce an accurate map; but a reconnaissance planimetric map can be compiled without any control at all. At least a skeleton of provisional horizontal control is most helpful, as well as a scattering of elevations (barometric) throughout the region. Moreover a provisional analytic aerotriangulation can be repeated later with the original photographic measurements when a denser network of accurate control is available.

ANALYTIC AEROTRIANGULATION

Analytic aerotriangulation depends on the use of an electronic computer (Harris, et al, 1962; Horsfall, 1964; Keller et al, 1964-1966; Umbach, 1966). The term "block adjustment" refers to the simultaneous computation and adjustment of all the overlapping photographs in an area (Tewinkel, 1966). A general system is in current operation in the U.S. Coast and Geodetic Survey.

The input data include the *x*, *y*, co-ordinates of selected images on photographic diapositives (colour as well as black and white) measured with an instrument called a comparator. The best accuracy of a comparator is about one micron (0.001 millimetre). The input also includes the control data and auxiliary data with an appropriate weighting system.

The output consists primarily of the *X*, *Y*, *Z* co-ordinates of all the objects corresponding to the selected images. These co-ordinates may be used like control in setting up a plotting instrument for map compilation, using either the same or different diapositives. The output also includes the *X*, *Y*, *Z* of each camera station, as well as the three orientation angles of each photograph, and an assessment of errors for images, for pictures, and for the entire system.

The criterion of the solution is the minimization of all the discrepancies of image measurement while judiciously fitting to all the control and auxilliary data. The mathematical basis consists of the fact that the three points, image, object and perspective centre, must lie on a common line for every image-object set; any failure to do so is attributed to an error in image co-ordinate measurement.

An attempt is made to take all known systematic errors into account with all the sophistication that may be necessary. These errors include lens distortion, film distortion, and comparator calibration factors. Also, earth curvature and atmospheric refraction are fully recognized.

Strips of photographs are not considered as strips although they may be initially analyzed in that manner for the preliminary phases of the computations. The block adjustment regards each photograph as a separate entity. The 60 percent side overlap affords

(1) an independence from the direction of flight,

(2) equal rigidity of adjustment in all directions, and

(3) a freedom from a need for cross flights.

Although the inclusion of auxiliary data have not yet been included in the C&GS programme, nevertheless they can be incorporated at any time now that the basic programme is operating smoothly. Thus it will be possible to specify:

(1) a ground distance (electronic) between two stations without knowing the co-ordinates of the stations;

(2) the azimuth (solar, polaris) between two stations in the same manner;

(3) the tip and tilt ($\omega, \varphi, \alpha, \beta$) of the camera from horizon photographs;

(4) the height (altimeter) of the camera above a point;

(5) the azimuth κ of the camera as obtained from a simultaneous solar camera;

(6) tip and tilt components, also from a solar camera;

(7) the $\underline{X}$, $\underline{Y}$ co-ordinates of the camera from SHIRAN; etc.

Several of these forms of data are available today; some are difficult or expensive operationally, and others are not yet manufactured.

The size of the computation for the adjustment of large blocks is somewhat startling; however computing costs are rapidly decreasing. The costs for small blocks seems acceptable even today. For example, on a fairly large computer the times and costs for two blocks of photographs were: 18 photos, 9 minutes, \$45; and 40 photos, 48 minutes, \$225. The costs shown here include a large portion of disk search time, whereas some larger computers charge only for purely computational time. It is logical to assume that one can arrange to apply the largest computer available to the problem of analytic aerotriangulation for a region of any size, and that the cost will not be prohibitive. (It is a general principle that the largest computers are the most economical). In the meantime, computer usage is being reduced greatly by applying optimization techniques so that, because the present programme is still new, the costs may be reduced significantly within the next few months.

The U.S. Coast and Geodetic Survey has in operation a series of aerotriangulation computer programmes all of which are either already published or are in process of publication (e.g., references Keller, Horsfall, Umbach). This series culminates in "Block Adjustment", which is prepared for 185 photographs and can be expanded to almost any number to fit the problem and the particular computer. Incidentally the programmes by Mr. C.T. Horsfall of Lagos, Nigeria (and supplemented by Umbach) were prepared for computation on a medium-size computer available in that country for applications to moderate-length strips of aerial photographs.

GENERAL DISCUSSION

Not only does the cost of computing block adjustments increase exponentially with the number of photographs, but also does the probable error of the results (in the absence of control) due to a quadratic-like propagation of undetermined small systematic errors. These errors cause a seemingly systematic deformation of the block (most evident in long narrow strips). For example, a strip of 18 photographs at 1:40,000 scale controlled only at the ends had a horizontal bow in the centre of 30 metres. The magnitude seems to be roughly proportional to the square of the number of photographs, and the effect is present in all three dimensions, perhaps somewhat independently.

Let us consider the variation in computer costs and in error for several different types of photography (repeating certain concepts from Mr. Harris' paper) for a hypothetical area 300 km by 300 km (Table 1).

TABLE 1

Estimated computer costs and residual errors for an area 300 km by 300 km

Type of Photography	Height (km)	Scale 1:	No. of Photos	Computing Cost	Error (m)	Target size(m)
Satellite photography	200	1,300,000	8	$24	3 to 5	40.
High Aircraft (with solar camera and altimeter)	23	150,000	525	$12,500	2 to 3	4.5
Aircraft (barometric elevation & 4 control points)	9	100,000	1100	$36,300	120.	3.

Horizontal and vertical control are considered to occur at the four corners. In the last example about 25 barometric altitudes are assumed to have been scattered throughout the area, as by using a helicopter (necessary even for the planimetric concept).

However computer costs are not the only elements to be considered. The costs for equipping and launching a satellite are quite large and probably can be economically applied only to very large regions such as a continent. The satellite scheme certainly will yield the highest accuracy in a most forthright manner. About the only ground preparation consists of establishing the targets. One would naturally want to use many, many targets, perhaps one every 10 km, to supply a dense accurate network on the ground at very low additional cost for future utilization.

The high aircraft approach seems also very promising. Capable airplanes and equipment are in process of manufacture.

The lower aircraft scheme has the advantage of being possible immediately with current equipment, and presents the lowest cost for the photography and highest cost for computing. The results consist of only a reconnaissance type of map which has limited applications. However, an immediate reconnaissance map, because of its timeliness, may have very great economic significance in the development of a region in the sense that a further delay of two to ten years for better maps might comprise a costly detriment to the progress of all the peoples of a region.

These photographs, in colour, at 1:100,000 scale enable the compilation of 1:50,000 scale maps using conventional stereoscopic instruments. Although the resulting maps may be reconnaissance in nature because they may show an erroneous geographic location, they nevertheless would be internally very consistent. Moreover they would depict all the drainage, roads, villages, mountains, and vegetative cover. Although contours as such would not have much value, nevertheless heights might have a datum error as small as 50 metres, depending on the density of the barometric elevations that had been provided. Surveys of sections of the region, or the entire region, can be readjusted later when more control is available.

It seems that satellite triangulation for control may actually be accomplished before classical geodetic surveys can be conducted. The eventual density and accuracy of satellite surveys is expected to be amply adequate for standard 1:50,000 scale maps.

CONCLUSION

Analytic aerial triangulation for a remote region is suggested by using any one of three types of aerial photography: satellite; ultra-high altitude aircraft; and conventional high altitude aircraft. The first two seem particularly attractive because of their very high accuracy and of the ease of computing. The last one may be attractive because of its almost immediate availability with conventional equipment for the timely production of maps for resources inventories and regional economic planning.

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