THE DEVELOPMENT OF PHOTOGRAMMETRIC COMPUTING SYSTEMS*

Randall D. Esten, Map Compilation Branch, Engineer Research and Development Laboratories

"Great fleas have little fleas upon their backs to bite 'em,
And little fleas have lesser fleas, and so ad infinitum.
And the great fleas themselves in turn, have greater fleas to go on;
While these again have greater still, and greater still, and so on!"[1]
So naturalists observe

SIMILAR to this problem in the world of parasites, scientific structure is a highly interrelated and interdependent set of definitions and standards. Through the years the science of photogrammetry has grown more exact, so that it has become possible to employ more extensively the accurate and concise methods and notations of mathematics. The availability of rapid means of computation has opened a broad avenue for the extension of control by analytical means.

Several investigations of analytical aerial triangulation systems are being directed by the Map Compilation Branch of the Engineer Research and Development Laboratories. These include an evaluation of the currently-employed British System of analytical aerial triangulation by the Army Map Service, an error analysis of analytical extension procedures by Cornell University, and the development of a combined analog-analytical system of triangulation designed for rapid operation by personnel with a minimum of training by Mr. Robert Zurlinden. In addition the Aerial Photography Branch at Wright-Patterson Air Force Base has assisted the Aerial Reconnaissance Laboratory of the Wright Air Development Center in preparing a set of fictitious convergent photographs.

Lt. Col. E. H. Thompson devised and the British Ordnance Survey employs an analytical photogrammetric triangulation system which utilizes aerial photography exposed by a camera equipped with a one centimeter grid reseau. The Automatic Computing Machine was successfully programmed to accomplish most of the required adjustment computations. This method has been successfully utilized by the Ordnance Survey for large scale mapping in the British Isles.

To determine the feasibility of utilizing this method for military mapping we have obtained the loan of a British F.49 Mark II 6-inch focal length Survey Camera equipped with a one centimeter reseau. In addition, a one centimeter reseau was manufactured and installed in the focal plane of a 6-inch focal length T-11 Camera. Flight strips at 20,000 feet over the Arizona Test Area will be flown with these cameras and the accuracy of triangulation will be determined utilizing the British method with the AMS UNIVAC, and the results will be compared with extensions of this same photography by analog means.

Besides the method devised by Thompson there are several analytical triangulation procedures which show considerable potential. The objective of our contract with Cornell University is to develop a system best suited for military operation. The study consists of three separate but related phases. Phase I is the study and evaluation of the various analytical aerial triangulation methods suitable for use with electronic computing equipment such as direction cosine methods, tensor transformations, y-parallax, relaxation methods etc. The adaption of one of these methods, or an entirely new method, devised or revealed as a result of the investigation shall be selected on the basis of suitability, for military use, the accuracy of extending horizontal and vertical control, and the time required for recording, preparing, and computing the data. This method selected will be proved by bridging control down a theoretically-computed eleven-model double strip.

Phase II will consist of an empirical

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[1] de Morgan, Augustus, *A Budget of Paradoxes*, Longmans, Green and Company, London, 1872, p. 377.

determination of horizontal and vertical accuracy throughout the strip as a function of strip length, amount and location of horizontal and vertical control, number and location of pass points per photograph, and displacement and misidentification of photographic images. The final phase will consist of programming and coding the procedure selected for UNIVAC.

All tests in the contract just described utilize theoretical data from fictitious aerial photographs. There are many good reasons for wanting to use such data at this phase of the investigations, but nonetheless, by so doing we exhibit our fear of one of the big bugaboos of analytical aerial triangulation, namely point misidentification. The avoidance of just this difficulty is only one of many features of the combined analog-analytical system being designed by Mr. Robert Zurlinden for the Laboratories. This is accomplished by use of a double, direct vision stereoscope with which the position of a pass point may be compared stereoscopically with its conjugates in as many as three different models in rapid succession. Although the ideas for a direct vision instrument were advanced by H. Grubb more than one hundred years ago, the prototype at Fort Belvoir is believed to be the first double, direct vision stereoscope constructed, and forms an integral part of Mr. Zurlinden's system.

In brief, this system consists of a special enlarging camera, the double, direct vision stereoscope and point plotter, coordinate measuring instrument, and an electro-mechanical computer. Selected portions of the negatives are magnified ten times in the enlarger, and the coordinates of a reference point in the enlargement with respect to the original negative automatically determined and recorded. Specific pass points are selected and marked in a stereoscopic examination of the models. The points are averaged, automatically corrected for lens distortion and film shrinkage, utilizing a reseau or any other referencing data, and recorded. At this stage all the initial data are recorded digitally. The electro-mechanical calculator is programmed to reveal, from arbitrarily chosen values of the six parameters of position and orientation of the air station, the x- and y-discrepancies of those pass points whose positions have already been determined, and the y-parallaxes of those pass points for which the positions are not known, but for which the directions from the previous air station have already been indirectly established.

These position discrepancies are set up synoptically in such a way that they can all be seen simultaneously by the operator of the calculator. By systematic and manually operated variations in the values of the initial parameters, the positional discrepancies are reduced to a minimum all over the field. This visual least-square adjustment can be quickly performed even with 24 pass points since there will be a discrepancy pattern to guide the operator in manually adjusting the controlling parameters. The final adjustment is recorded on a new set of punch cards and the work proceeds with the next photograph.

The fictitious nearly vertical aerial photography to be employed in the investigation by Cornell University was computed for the Air Force on the Harvard University Mark I Computer. It consists of survey and photographic coordinates for a double strip of twelve photographs per strip with twenty-five points per photograph. The assumed nominal flying height was 40,000 feet, the camera focal length six inches, a base height ratio of 0.6, and the maximum tilt 4°30′. The elevations of the 225 ground points are distributed with mean 850 feet, standard deviation 500 feet, and maximum value 5,000 feet.

Similar fictitious convergent photography is being prepared by the Aerial Reconnaissance Laboratory of the Wright Air Development Center. Strips of actual photography exposed over the Arizona Test Area will be employed when we have learned all that is necessary from the fictitious photography. It is hoped that we can encourage others engaged in similar investigations to use these same strips of fictitious and actual aerial photography so that we may all have a common basis for comparing our extensions.

DISCUSSION

MR. SHARP. A few minutes will be devoted to questioning and discussions.

QUESTION: I have a question for Dr. Schmid. At what stage in the procedure and subsequent procedures is correction for position of the point due to distortion of the film focal plane taken care of?

DR. SCHMID: The *X* and *Y* photographic measurements are corrected by adjustment, plus or minus. This operation can be programmed and performed by a digital computer.

QUESTION: I would like to ask Mr. McNair for a little more information on these medium capacity computers. Are they operated on magnetic tape like that in Univac?

MR. MCNAIR: With the machine which we have on order, the operation will be performed from punch cards, but on a magnetic drum. That is the memory device which will record, or rather which will store, renumber and be able to recall these numbers, 1,000 to 2,000 numbers, ten-digit numbers—that is the drum which I showed in the slides; but the operation is performed and the data originally put in from punch cards.

QUESTION: Could you give me an idea of the cost per month for the rental of that unit, the complete unit?

DR. HERGET: About $3,500 per month.

MR. SHARP: Because we have been running short on time and the group is too large for effective discussion, the meeting at this time will now be closed. Then any in the group can come up and talk with the various members of the panel on any particular problem that they wish to discuss.

Most of this group were trained in photogrammetry. They are thinking and working toward making computing systems of economic usefulness in map producing organizations. They deserve your support and confidence as they progress toward automation in photogrammetry.

NEWS NOTE

New Plotter to Cut Costs of Surveying and Mapping

Costs of producing surveys and maps for a wide variety of industrial and engineering uses will be greatly reduced through use of a new aerial mapping instrument announced Sept. 27 by the Bausch & Lomb Optical Co.

Known as the Balplex Plotter, it will produce maps from aerial photographs with contour intervals as small as 1 to 2 feet. When placed in the plotter, reduced transparencies made from the photographs produce a three-dimensional view of the ground such as might be seen by a giant whose eyes were hundreds of feet apart. The new instrument makes possible producing maps from these photos at a fraction of the cost and time of ground surveying.

In 1945, Bausch & Lomb introduced an aerial mapping instrument that sold for about $10,000, was known as Multiplex Mapping Equipment, and is today one of the leading instruments in the industry. The new Balplex instrument sells for approximately $4,250 and is expected to produce another major cut in aerial mapping costs.

The Balplex Plotter consists of a precision table over which are mounted two projectors. Photographs taken from high-flying airplanes are converted into transparencies and inserted into the projectors. When viewed with special stereo glasses, the two projected images produce a three-dimensional picture of the earth's surface. The operator then traces the ground image with a tracing table which records the surface of the ground at a particular level, producing a contour line. The table is then readjusted for each subsequent contour line.

Many design advancements, such as a unique light control, give the instrument greater accuracy and speed of operation. The projector design incorporates an ingenious ellipsoidal reflector developed by R. K. Bean of the U. S. Geological Survey. It was originally used in Twinplex Equipment, manufactured on special order by Bausch & Lomb for U.S.G.S.

The projection transparencies are 110 mm. square—a size which permits retaining all necessary details in the original 9×9 aerial photograph. Accurate maps with scales as large as one inch to 50 feet can be produced. Maps can be made from photos taken from heights as low as 1,000 feet or as high as 35,000 feet.

The projector frame can accommodate two additional projectors which sell at $2,160 a pair. Balplex projectors also can be mounted on frames of the present Multiplex systems.