Photogrammetric Instruments for the Army

By CAPT. CLIFFORD J. MUGNIER

Corps of Engineers, United States Army

THE advantage of using photographs for mapping has been recognized for more than a century and it has been realized that, as more sophisticated methods develop, less surveyed ground control would be needed to produce an accurate map. One of the major contributors to the high cost and slow production of mapping has been the extensive time-consuming surveying required in the field to establish accurate control for a mapping project.

Aerial photographs were used in the American Civil War for reconnaissance purposes, but only to a limited extent, one reason being the shortage of balloon pilots. In Europe, applications for photogrammetry were being considered, and on July 25, 1891, a patent was granted for "A New or Improvised Apparatus for Obtaining Bird's-Eye Photographic Views." The contraption was an artillery shell containing a parachute-mounted camera for photoreconnaissance. While this patented "apparatus" was probably not produced, some feasible inventions were manufactured—mostly in Europe. In 1917, the 29th Engineer Topographic Battalion was organized. It carried out many aerial photographic mapping tests and furnished most of the cadres for the World War II topographic units. Their equipment included the portable topographic stereoplotter (Figure 1).

During World War II, vast areas were photographed and mapped with a specially designed aerial mapping system called the Metrogon, a 6-inch focal length vertical camera. The triangulation of this photography was done on Multiplex Long Bars—a series of Multiplex projectors that recreated long flight lines of photographs (Figure 2). The tip, tilt, and swing were compensated by graphical and numerical methods. After the war, the Army acquired some photogrammetric instruments expressly designed for aerotriangulation. These instruments were constructed to extremely close tolerances and attained remarkable accuracies. The principle of collineation was extensively used and, when expressed in matrix notation, a rotation matrix was included to account for rectification of tip, tilt, and swing of the airplane's axis when the exposure was taken.[1]

In the early days of photogrammetry, the orientation of an overlapping pair of photographs (stereo pair) to each other and to the ground was done mechanically. The principle of collineation was synthesized with metal rods, the photographs were physically rotated in reference to each other and to the plot-

[1]The general solution is,

$$\begin{bmatrix} x \\ y \\ -f \end{bmatrix} = \begin{bmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

Where the left side of the equation expresses the three-dimensional Cartesian co-ordinates of the photo image and the right side is a matrix product of the camera orientation and the three dimensional Cartesian co-ordinates of the ground point imaged. When the equation is applied to the principle of stereoscopy, measurements taken from a pair of overlapping photographs can be used for deriving the latitude, longitude, and elevation of previously unknown points.

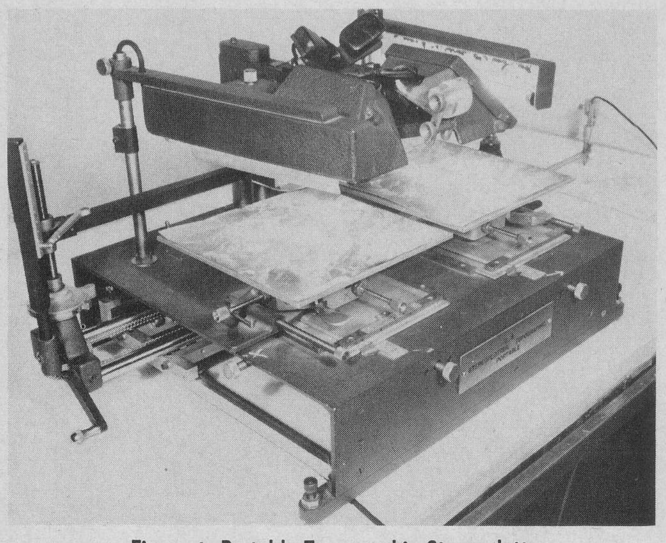

Figure 1. Portable Topographic Stereoplotter

Figure 2. Multiplex Long Bar

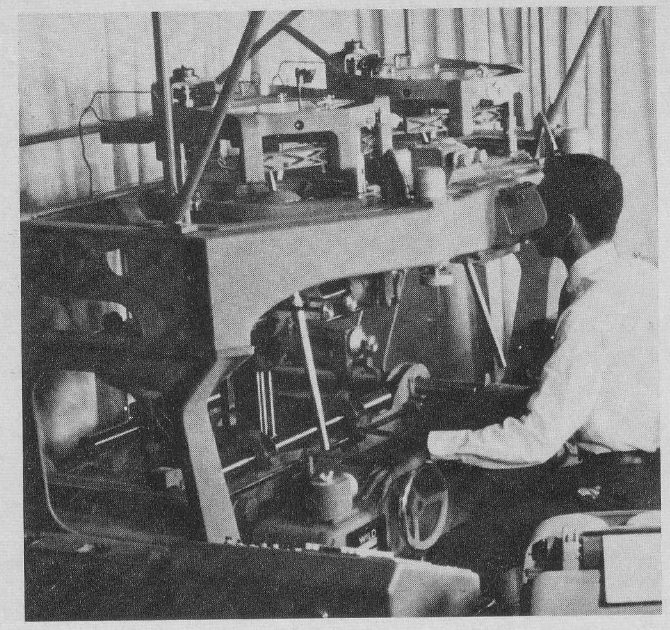

Figure 3. Wild Autograph A7

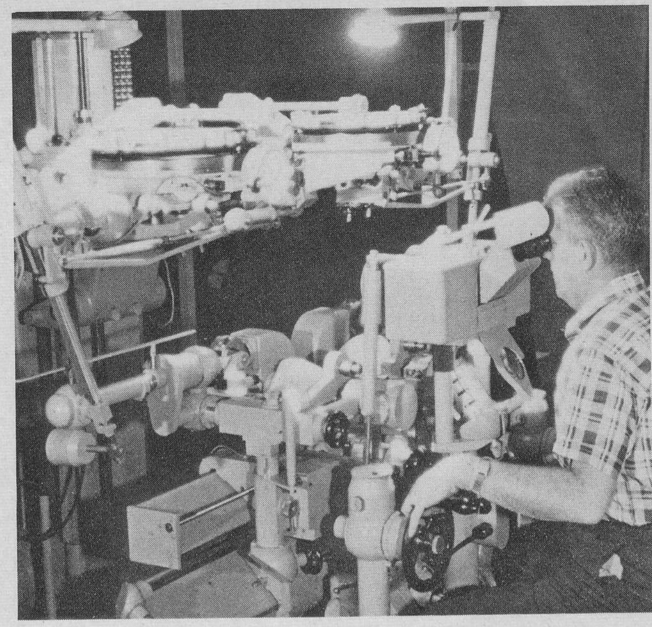

Figure 4. Zeiss Stereoplanigraph C8

ting table, and the instruments used were as mechanically sophisticated as a chronometer. Such instruments were manufactured by Zeiss, Wild, Société Française d'Optique et de Méchanique, Nistri, Hilger-Watts, and others—an almost exclusively European industry. Few first-order photogrammetric triangulation instruments were produced in the United States.

The triangulation instruments such as the A7 Autograph (Figure 3), Stereoplanigraph C8 (Figure 4), and others were used by the Army Map Service, the predecessor of TOPOCOM,* and some are still occasionally used. These instruments are accurate and reliable, preventive maintenance is regularly performed by TOPOCOM technicians, and there is virtually no need for factory repair. Some of the precision-engineered parts are unavailable, and new parts are produced by TOPOCOM master machinists. Such instruments, however, are not always suitable for present Army mapping requirements because camera types, flying heights, and control densities vary from one mapping project to another. But until the 1960's, Army photogrammetrists had to use these instruments and restrict the variety of imaging systems to those that could be handled by them.

*Army Topographic Command.

ANALYTICAL AEROTRIANGULATION

With the development of electronic digital computers, photogrammetry began to change drastically. Army Map Service was one of the first federal agencies to acquire such a computer, and with it mathematical formulae could be used which previously had been too time-consuming to be practical. The triangulation instruments on hand used mechanical and optical processes to reconstruct the bundles of light rays entering the camera, and there were inherent inaccuracies due to the mechanical linkages. These inaccuracies were unavoidable unless the triangulation were performed in an abstract sense. The advantages of utilizing a high-speed digital computer for a math-

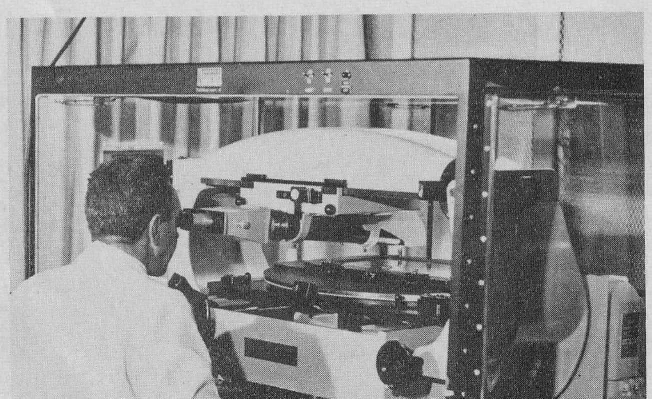

Figure 5. Mann Monocomparator

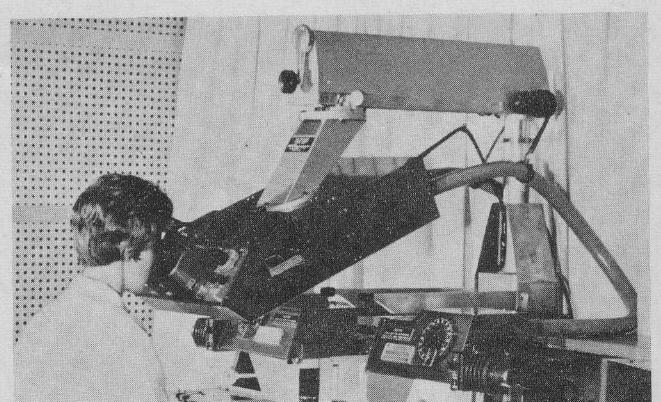

Figure 6. Optomec 571 Stereocomparator

ematical approach to photogrammetry were soon recognized[2] and the groundwork was laid for a mathematical analysis of the photogrammetric problems in vector notation. Papers were written in matrix notation mainly because of the ease in programming matrices for computers and the simplicity of expression. After practical application, a mathematical approach (analytical) was found to be faster than with the use of the opto-mechanical approach (analog), in addition to being more accurate. Thus a new kind of photogrammetric instrument was produced for analytical aerotriangulation.

With the introduction of analytics, a new term became familiar to the photogrammetrist: the micron (μ)—one 1/1,000th of a millimeter (10^{-6} meter)—now called the micro-meter (μm).

There are now two basic schools of thought concerning the types of instrument systems used. One school adheres to the principle of making marks in the emulsion of the photograph where control is desired and then measuring the marks one photograph at a time on a monocomparator (Figure 5). The second school believes in measuring two photographs at a time on a stereocomparator and omitting the marks (Figure 6). While this seems to be a minor point, among photogrammetrists the subject leads to heated discussions. Vast sums of money in research and development have been spent on this controversy with the final objective being the improvement of speed and accuracy in mapping and reduction of production costs. The outcome probably will be a compromise, assuming the mapper has the facilities to use both systems.

STEREOSCOPIC MARKING

In the early 1950's, the Wild Heerbrugg Company produced the PUG (Figure 7), an instrument for marking photographs stereoscopically, with the basic idea that this is the most accurate method of transferring points for aerotriangulation. The image point is permanently marked with a rotating drill, and a permanent reference for the control point is maintained on the photograph. At some other time, the points may be read on a monocomparator, one photograph at a time. The two main advantages to this approach are that, as photogrammetric instruments go, a Wild PUG is relatively inexpensive, and a monocomparator is the least expensive instrument on which to make co-ordinate measurements for analytical photogrammetry. The disadvantages of stereocomparators (reading two photographs at a time) are the high cost of the stereocomparator and the poor results achieved in attempting to obtain permanent records of unmarked control points.

[2]By Dr. Hellmut H. Schmid of the Army Ballistic Research Laboratories at Aberdeen, Maryland.

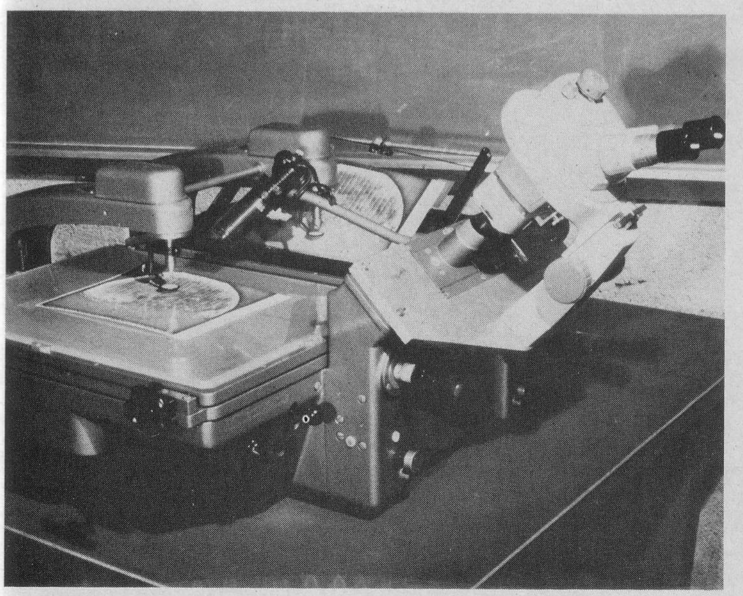

Figure 7. TOPOCOM-modified Wild PUG

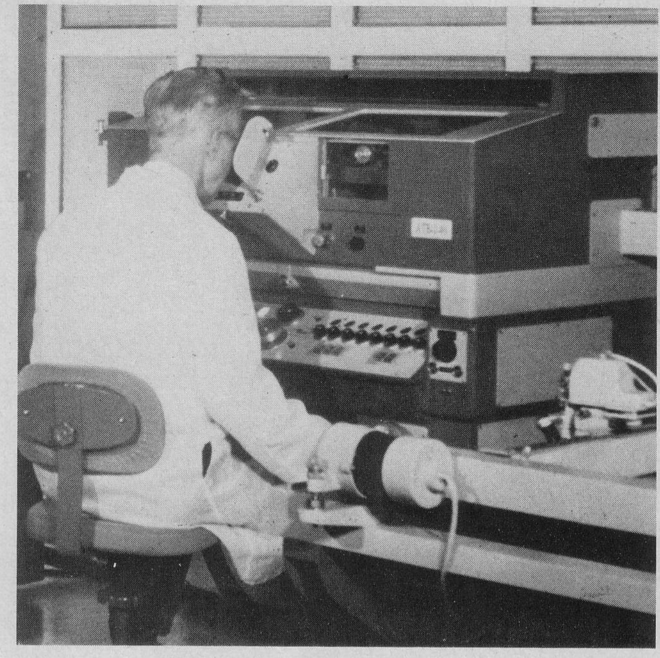

Figure 8. Nistri OMI-Bendix AS-11a

When a photograph is physically marked, part of the image is obliterated, and this will prevent the photogrammetrist from consistently measuring the point on a monocomparator. Stereocomparator operators do not have this difficulty, and final vertical accuracies are many times better. The reason for this is that vertical positions (elevations) are a component of x-parallax, the shift in position of a particular image on two or more photographs with less than 100 percent overlap. When the image is partly obliterated by a mark in the emulsion, the x-parallax cannot be measured as accurately as with unmarked photographs on a stereocomparator. The total time expended by either method is about equal.

AUTOMATED COMPARATORS

The next logical step was to attach a digital computer to a stereocomparator, thus bringing the development of photogrammetric instruments full circle, but on a higher level. With the computer and a plotting table, the end product of the stereocomparator is the same as that of the A7, C8, et cetera—a finished, contoured manuscript. With the increased precision of the instrument, a more accurate product is obtained and a wider tolerance for imaging systems is provided. Since the stereocomparator is combined with a computer, the possibilities of using different triangulation techniques with a variety of sensors are limited only by the ability of the programmer. Computations are made by push button, and movement about the stereomodel is controlled with hand- or foot-operated wheels (Figure 8).

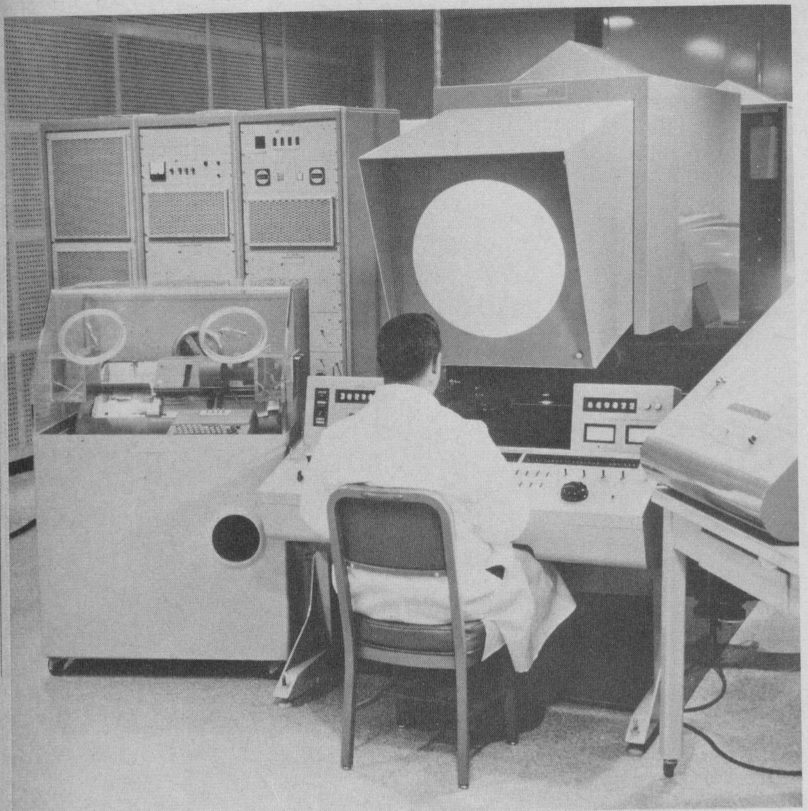

Figure 9. Semiautomatic Co-ordinate Reader (SACR)

Figure 10. Nistri OMI TA3/P Stereocomparator

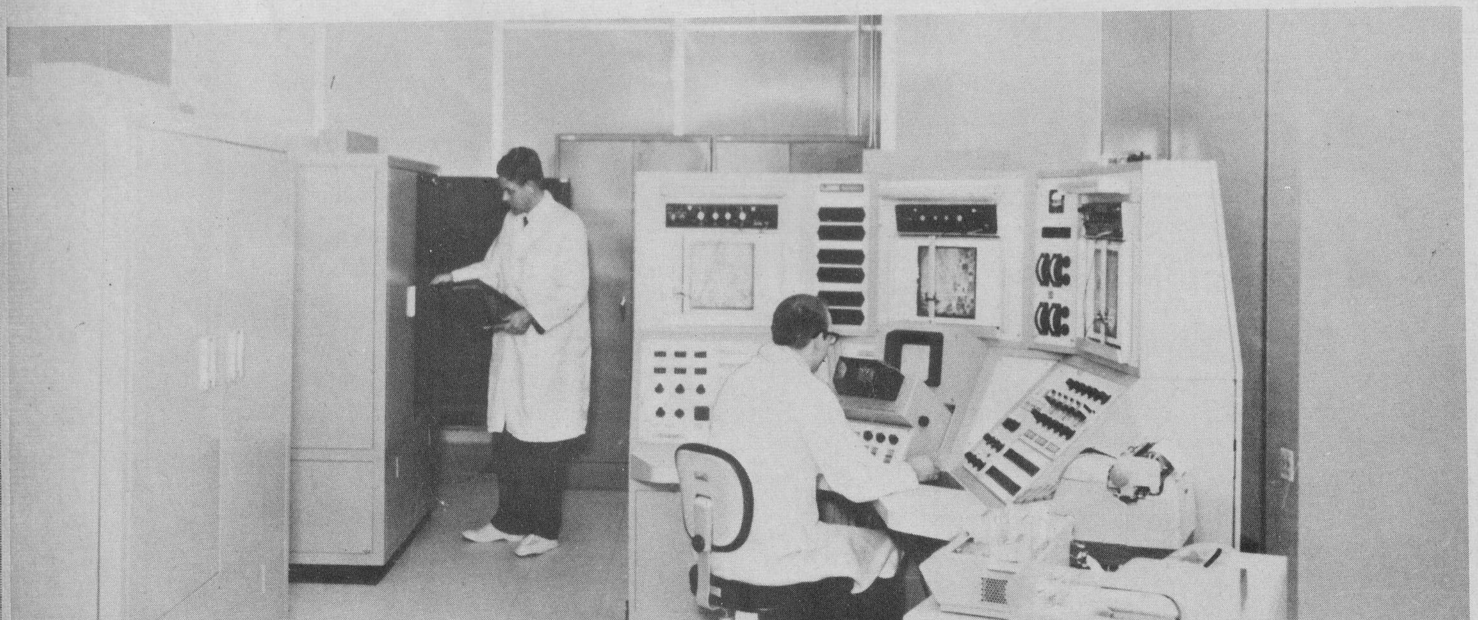

Figure 11. Automatic Point Transfer Instrument (APTI)

To speed up the triangulation process, the physical movement of the photograph plate in a monocomparator was automated using a "pre-position deck" of punch cards. For repetitive tedious tasks such as calibrating grid plates, a total manual measurement need be made only once. Any subsequent recalibration of the comparator or other identical grid plates can be measured automatically with the original deck of punched cards. This automated comparator was one of the first photogrammetric instruments to have air bearings (Figure 9). With these bearings there are reliability of operation, negligible friction, and assurance of precision. Granite was used first for a base, and, on later instruments, ferrous alloys. Because of the weight, the air-bearing instruments are moved very seldom. An added feature of some types of air-bearing instruments is that the surfaces of the bearings are hermetically sealed, and clean-room procedures may be less stringent than normally followed. The seal is achieved by the use of dust baffles and a supply of super-clean compressed air filtered to catch particles larger than 0.6 micro-meter (μm).

The further step of using three photographs instead of two has been considered for some time and has been put in operation at TOPOCOM. The advantage is that a third photograph strengthens the mathematical solution and acts as a check for misidentified points. For this process, a three-stage stereocomparator (Figure 10) has been developed. The operator views an overlapping pair of photographs as in the stereocomparator, but can also view the adjoining photograph in the next overlapping stereomodel. In actual production, the accuracy is more than doubled.

The final product in this development is the Automatic Point Transfer Instrument (APTI)[3] (Figure 11), a three-stage stereocomparator having the best features of all previously built photogrammetric instruments. This instrument has three air-bearing tables (or stages) and is more reliable than its predecessors. After mounting three overlapping photographs, the operator need view only one, and when the instrument is moved about that photograph the other two automatically follow. If a record is desired of a particular point, the instrument can melt 40-μm marking holes in the emulsion on all three photographs with an accuracy of better than 2 μm. When grids are periodically used to recalibrate the instrument, the operation is automatic, based on a pre-position deck of punch cards. The instrument is the fastest built so far, and is the most advanced piece of operational equipment for analytical aerotriangulation.

AUTOMATED COMPILATION

In keeping with the progress in triangulation instruments, compilation equipment has also been automated and is known as the Universal Automatic Map Compilation Equipment (UNAMACE)[4] (Figure 12). When a vertical aerial photograph is viewed, the center of the photograph is relatively undistorted in relief, but vertical changes in terrain are displaced towards the horizontal in increasing degrees away from the photograph center; and, when the photograph is tilted, the problem becomes more complicated. With the triangulation data furnished, the UNAMACE will rectify all systematic distortions and relief displacement automatically and reprint a photograph as if it

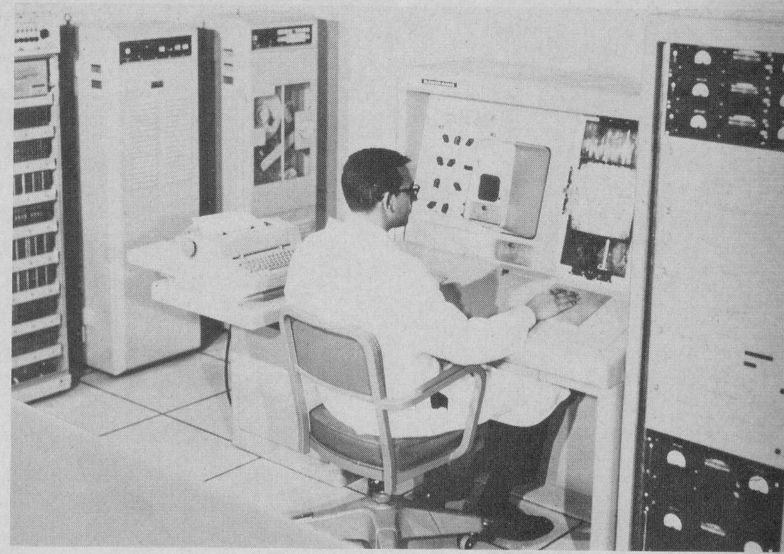

Figure 12. Universal Automatic Map Compilation Equipment (UNAMACE)

were being viewed from infinity, as maps are normally depicted. In conjunction with this process the UNAMACE will provide a graphic, from which contour lines are easily interpreted. By adding an overlay giving place names and other cartographic annotations, the final product is an orthophotomap.[5]

Analytical photogrammetry is still a base-plant operation for the Army. Future requirements call for a means of analytical triangulation in the field. One promising candidate for this is a portable multilaterative comparator (Figure 13). The instrument is a monocomparator with high accuracy, unaffected by environmental changes, and inexpensive.

The only economical way to map a large area is with photography, and the most efficient application of photogrammetry is with analytics. The continued development of analytical photogrammetric equipment is directed to increases in volume and efficiency integrated with improvements in accuracy. The past development of photogrammetry has been considered with relation to improvements in mapping equipment. This review brings up to date the TOPOCOM equipment available and in use today.

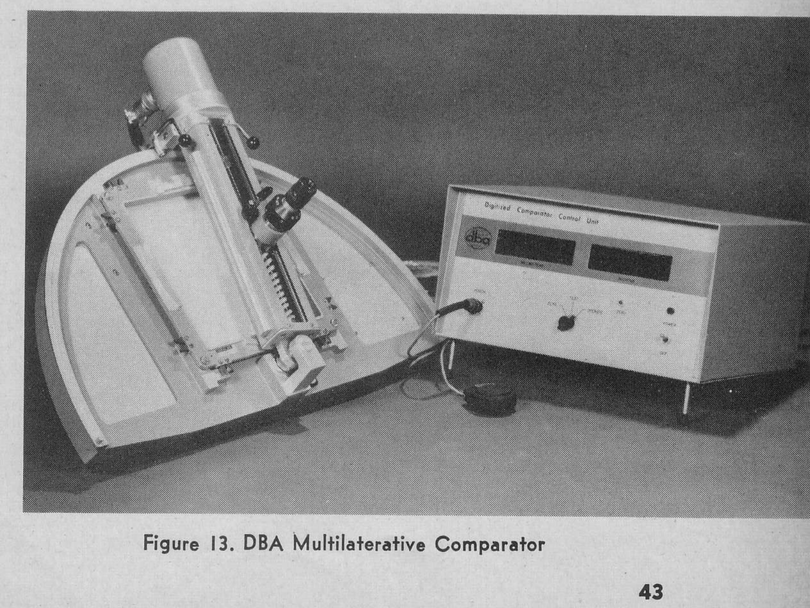

Figure 13. DBA Multilaterative Comparator

[3] See M.E. May-June 1971, p. 198.

[4] See "UNAMACE," by Edward F. Burzynski [M.E. Mar.-Apr. 1969].

[5] See "Mapping in Southeast Asia," by Col. Edward G. Anderson, Jr. [M.E. July-Aug. 1971].