Development of Automated Photogrammetry by U.S. Military Map Makers

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FROM THE TIME of the first observation balloons in the Civil War to cameras attached to flimsy biplanes in World War I, through the increasing sophistication of aerial photography in World War II, to today's high altitude cameras, military photogrammetrists have pioneered techniques and applications of this vital technology. Spurred by the unique requirements, and capabilities, of the Armed Forces, professionals of the Defense Mapping Agency (DMA) continue to lead in this increasingly sophisticated field.

In photogrammetry, as in so many areas of modern society, it was the application of computer technology that spurred the revolutionary developments which continue today. DMA's predecessor agencies in the three services were active in utilization of computers almost from their inception, with the third production model of UNIVAC I put on line at the Army Map Service (AMS)—to be used for triangulation of aerial photography.

At the same time, semi-automated photogrammetric equipment captured from the Germans after World War II was brought to the United States and for some years was used by military photogrammetrists until American automated technology developed.

We all accept that the fundamental task of photogrammetry is to establish precise relationships between the image space and the object space of a set of metric photographs. In an analog stereoplotter, this relationship is established and maintained by manually-controlled mechanical linkages between photographs and their projected images. In an analytical stereoplotter, the relationship is derived and controlled by a digital computer. As a result, the object-image relationship can be attained more accurately at any given point, and can be obtained even in the case of geometrically complex image systems.

Development of analytical photogrammetry was carried out along parallel lines by the Army Map Service and the Aeronautical Chart and Information Center (ACIC) during the late 1950s and early 1960s. Since mapmaking functions of the Army and Air Force, plus the Navy's Hydrographic Office, were consolidated into the Defense Mapping Agency in 1972, these courses have merged, and both early technologies are still utilized by DMA. In fact, it is generally conceded that continuing new developments in analytical photogrammetry are but improvements in the technology developed in the '50s and '60s.

The two systems developed by these military elements were the Analytical Stereoplotter at the ACIC and the Universal Automatic Map Compilation Equipment or UNAMACE at the AMS. Their development follows.

THE ANALYTICAL STEREOPLOTTER

The origin of the analytical stereoplotter began as a solid technical concept published by Dr. U. K. Helava, of the National Research Council in Canada, and is today one of the principal mensuration production instruments at the Defense Mapping Agency.

After Helava first proposed the possibility of constructing an analytical stereoplotter in 1957, Fairchild, Bendix, and Otto Mechanica Italiana (OMI) teamed up to develop the first practical implementation of this concept, the Analytical Plotter 1 (AP-1). The Air Force funded this effort through Rome Air Development Center (RADC) for ACIC.

Design of a second generation AP-2 began even before delivery of the AP-1. This second plotter, built by Bendix and OMI, was delivered to RADC in 1961 as a prototype. Production models, known as AS-11A's, were delivered to ACIC in 1963 and to AMS in 1965. An AS-111B1, capable of automated image correlation, was delivered to ACIC in 1968, thereby providing ACIC with a capability which AMS was obtaining with the development of the UNAMACE.

DMA's first analytical stereoplotters were designed primarily for graphic output of contours or other cartographic data via coordinatographs, but did have a limited ability to output point coordinates in digital form. During the 1970s, DMA was assigned the task of compiling Digital Terrain Elevation Data. To meet this requirement, the AS-11A's were upgraded to AS-11AM's, between 1977 and 1980. Upgrading consisted of replacing the computers and tape drives, adding on-line data storage, and networking the plotters into Pooled Analytical Stereoplotter Systems (PASS), in which groups of nine stereoplotters are linked to a central computer. Operationally, the shift from graphic to digital output means that the operator compiles elevation profiles rather than contours.

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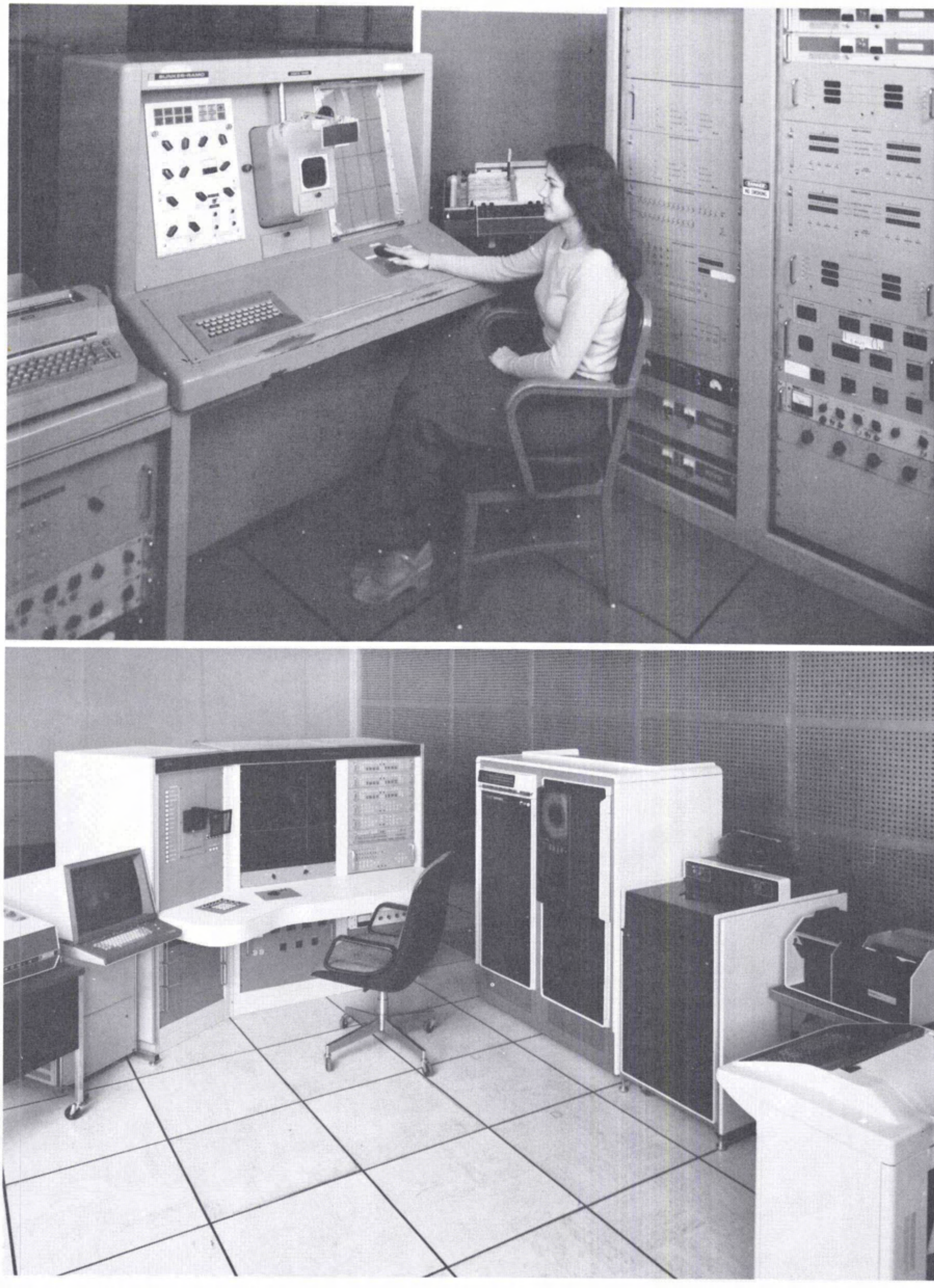


(1) Early configuration of the Universal Automatic Map Compilation Equipment (UNAMACE) and (2) today's modern work station at the Defense Mapping Agency's Hydrographic/Topographic Center in Brookmont, Md.

Since its inception, the analytical stereoplotter has been operated as a stand-alone universal photogrammetric instrument. It is a self-contained system consisting basically of a stereoplotter, a control computer and interface, and a plotting table. The control computer for each stereoplotter has been dedicated to the realtime and supporting computational tasks which are fundamental to the operation of the system. While the size of the supporting computer has changed through the years as modifications to the instruments have been made, the systems have remained in a stand-alone operation.

With the demand for digital cartographic data at the Defense Mapping Agency increasing, modifications to the computer of the conventional analytical plotter have been required for efficient and economic digital data production. Each analytical plotter must be augmented with a suitable computer peripheral device to store the large number of terrain coordinates extracted from the model.

DMA acquired additional analytical stereoplotter systems between 1980 and 1983. These systems are based on a new model stereoplotter, the AS-11P. The new PASS's are not required to produce graphic products, and include no coordinatographs. They are provided with interactive graphic CRT displays which allow online editing of the elevation data.

DMA is currently pursuing the development of analytical stereoplotters capable of superimposing graphics into the stereoimage seen by the operator. These systems will permit rapid compilation of three-dimensional digital feature data, as well as allowing editing of digital data in the context of the imagery from which it was compiled.

Another current development is the Digital Stereo Comparator/Compiler (DSCC). This is essentially a stereoplotter which accepts digital imagery as input. The DSCC can be used both for manual compilation of digital terrain or feature data, and for automatic compilation of digital elevation data using digital image correlation.

The UNAMACE

The UNAMACE concept was conceived by the Geodesy Intelligence Mapping Research and Development Agency (now the U.S. Army Engineer Topographic Laboratories) and built under contract by the Bunker-Ramo Corporation in 1965. The initial operational design of the UNAMACE called for the simultaneous scanning and printing of overlapping aerial photographs in a one-step operation. This system, unlike most other hardware equipment, was built as a production model and not as a prototype. The system was configured to include four precision *x-y* positioning tables, four table electronic cabinets, an operator's console, a two-bay electronic cabinet, a digital computer with 16k bytes core memory, a controller used to input operational programs and data to the computer, a magnetic tape drive unit, and a magnetic tape controller.

In the summer of 1967, the original hardware entered production, to produce an orthophotographic base for map compilation and elevation data, in the form of an altitude chart comparable to a drop line, for contour production. Since that time, production usage identified several areas where follow-up research and development were necessary to improve the overall production process by utilizing the digital elevation data for contour development and by enhancing the quality of the orthophotograph.

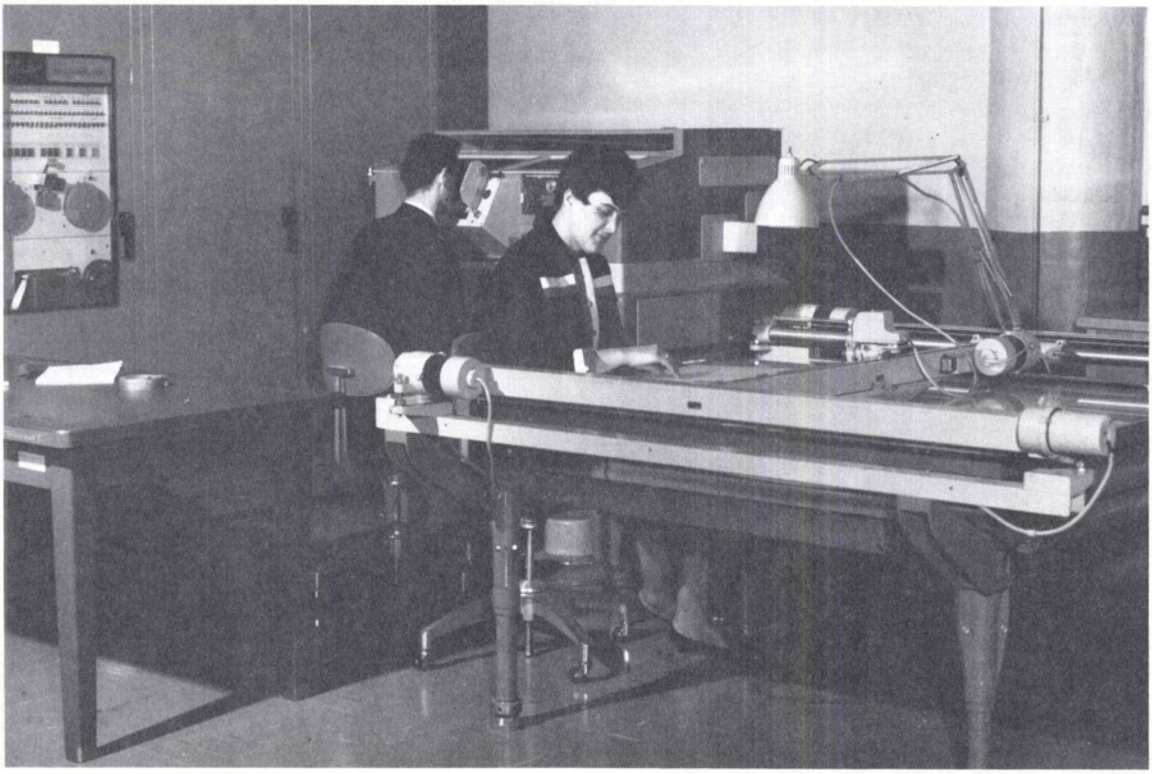
Development of an "Automatic Gain Control" (AGC) system minimized difficulty with fluctuating light source by maintaining light emission from a flying spot scanner at a constant amplitude, irrespective of the spot position on the face of the CRT. The basic purpose of the AGC system was to improve the orthophotograph image by minimizing density deviations on the output product. However, the most significant benefit derived was the increased accuracy of the generated elevation data.

During the summer of 1971, the use of the UNAMACE-derived digital elevation data to produce contours was introduced into the production process. It was during this time that a program was written for use on the UNAMACE to permit printing on orthophotograph from elevation data generated on the UNAMACE. With development of these two capabilities, emphasis was then placed on digital data.

With development of off-line processing of digital data to generate contours, it became critical that the digital data be recoverable. Since the original tape recording units were unreliable, they were replaced with vaccuum-type units. The vacuum units provided both increased reliability in the successful retrievability of the digital data and improved ease of operation.

The UNAMACE system was controlled by a Bunker-Ramo computer with 16k bytes core memory. The original compilation program was written in 1965 and later modified to expand its capabilities. The 16k program could not be further modified without deleting certain desirable routines, so memory capacity was extended to 32k.

With continually increased use of the orthophotograph, it became necessary to improve the printing system. Prior to development of the off-line Orthophoto Printing System (OLOPS), printing was done on seven separate UNAMACE systems. Each system was unique, and the printing characteristics were almost impossible to control. Consequently, the orthophotograph printing function was removed from the UNAMACE and a separate system was designed specifically for the printing of high resolution orthophotographs with uniform image tone. The OLOPS was designed to utilize the digital elevation data generated by the UNAMACE (after the data had been processed through UNIVAC 1108



AS-11 Stereoplotter used at Defense Mapping Agency Aerospace Center in early 1960's.

The AS-11 Analytical Stereoplotter is used at Defense Mapping Agency's Hydrographic/Topographic Center in Brookmont, Md., and at its Aerospace Center in St. Louis.

smoothing program) to recreate an orthophotograph of higher resolution and overall control of density. The OLOPS operates at approximately eight times the speed of the UNAMACE by increasing print width size from 250 by 500 mm to 500 by 2,000 mm. Development of the OLOPS and the x-y profile validation device led to the ultimate removal of the printing of orthophotographs and altitude charts on the UNAMACE.

The original UNAMACE software was written in assembly language. Modern photography demanded more sophisticated mathematical models, which in turn placed heavy demands on available core memory. System reliability became a problem as the UNAMACE approached its tenth year in production. For these and other reasons, in 1979, DBA Systems, Inc. was contracted to upgrade the UNAMACE systems. The contract provisions included replacing the UNAMACE's computer and its peripherals and refurbishing the old tables to bring them back to original accuracy specifications. Later, the UNAMACE host computer was replaced with a Data General Eclipse 250 with 265k bytes core memory.

Today's upgraded UNAMACE software was rewritten in FORTRAN V instead of the original assembly language (FORTRAN computer version 6.0). The applications programming is divided into eleven major areas, which are in turn further subdivided, thus giving the software valuable modularity. The eleven major modules are (1) initialization, (2) interior orientation, (3) relative/absolute orientation, (4) roam (allows operator to roam over model outlining adverse areas, etc.), (5) compilation, (6) rejection, (7) edit/output (edit operations and creating output tapes -bypassing UNIVAC processing and generating OLOPS output tapes directly), (8) calibration, (9) diagnostics, (10) restart (can restart system following shutdown, retaining original interior orientation), and (11) exit (orderly system shutdown). The upgraded UNAMACE software is menu-driven, and off-line and on-line profile editing are possible.

This upgraded UNAMACE final hardware was accepted between July 1981 and March 1983. Final software was accepted in June 1983.

Conclusion

Clearly, development of automated photogrammetry has been vital to performance of the Defense Mapping Agency's mission of providing mapping, charting, geodetic products and services and digital data to the Armed Forces. Today, DMA's annual output includes upwards of 40 million printed paper maps, charts, and other products—plus millions of square nautical miles of digital data on the Earth's surface, used for navigation and guidance by all military elements and most modern missile and weapons systems. These requirements will continue to grow and their sophistication to increase.

At the same time, the technologies developed to meet increasing military requirements will become ever more useful to the civil sector, as the application of analytical photogrammetry becomes more widespread. These peaceful applications of advanced military developments will work to the benefit of all mankind.