*Automatic Photogrammetric Instruments**

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ABSTRACT: *Developments in automatic photogrammetric instruments, as given in sixteen presented papers, are reviewed for the Tenth Congress of the International Society of Photogrammetry in Lisbon. These developments include servo-driven plotting tables, new and improved methods of differential rectification, computer-driven plotting equipment, automatic mapping from projection instruments and basic stereometers, and the automation of image registration. Several trends are noted, particularly the tendency toward large and complete mapping systems, the increasing importance of numerical photogrammetry, and the increasing appreciation of human abilities and logical decision.*

INTRODUCTION

BANDWIDTH, cross-correlation, flying spot scanners and feedback! New words have entered the photogrammetrist's vocabulary and with them new concepts in the extraction of topographic information from aerial photography and in the presentation of these data for human and machine use. It is not by chance that these words all have electrical or electronic connotation; for photogrammetry, long a composite field, now borrows heavily on electronics and with this investment receives the impelling trend toward automation. Stereo operators, dozing in their booths, long ago held the vision of automatic photogrammetric instruments; and the engineers, with new tools at their command, have brought forth many examples of automation for us to savor and judge. To savor and to judge; but not to reject completely, because increasing automation is now a fact of life; and it must now be a wide-awake photogrammetrist who beholds automatic photogrammetric instruments in operation.

MAN AND AUTOMATION

In his paper, "The Limits of Man and Automation in Photogrammetry," Professor K. Schwidefsky of the Technische Hochschule, Karlsruhe, investigates the basic functions in which man and automatic photogrammetric equipment compete; optical perception, memory capacity, logical operations, capability of learning, and capacity for abstraction; listed perhaps in order of their degree of difficulty for both competitors. This analysis affirms the fact that the human eye and brain are masterpieces of construction and that artificial systems still have a large gap to close in most areas of comparison, particularly in size and weight. But the gap is constantly narrowed, and a resurvey would show it to be smaller today than at the time Professor Schwidefsky's paper was written. Neurophysiologists have discovered structural similarities between logical switching in the nervous system and in technical systems. Here again engineers would like to approach the capabilities of the human system. The technical systems are likewise second best in the processes of learning and abstracting, but great strides have been and are being made.

If man generally exceeds state-of-the-art automation in these basic functions, why automate? In each project, whether it be purely scientific, economic or military in nature, there are certain goals and objectives toward which we work. Naturally these goals and objectives differ amongst the categories mentioned. For a specific project we may be looking only to advance the state-of-the-art, or to do something more cheaply, or more accurately or more quickly, and we must consider the degree of automation which will best meet our criteria.

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Professor Schwidefsky, in his paper, defined five steps of automation arranged in order of increasing performance which may generally be described as computers, analog-to-digital and digital-to-analog converters, signal orienters, signal correlators, and finally form recognizers. Photogrammetric examples of the first step are the classical stereoplotters and the more recent analytical plotters, and of the second step, automatic coordinatographs. Equipment representing the third and fifth steps exist only as experimental models; but the fourth step is illustrated by several instruments to be discussed in this paper, the best known of which is the Stereomat.

Servo-Driven Plotting Table

An example of the judicious application of new techniques to familiar problems is illustrated in the paper of Professor C. Trombetti, Instituto Geografico Militare, Florence, entitled, "Drawing Tables Driven by Electronic Servos for Analogical Photogrammetric Plotters." In this development synchro-transmitters are used to transfer X- and Y-movements from the plotter to synchro-receivers on the independently mounted plotting table. The plotting surface of this table, the 030M, is exceptionally large, being 200×150 square centimeters. In order to avoid loss of transmission accuracy, a double-speed synchro-transmission is employed. Preliminary results showed that positioning accuracy was well within allowable map error, a result which could not be achieved with any other type of servo system.

Differential Rectification

Another area which has received much attention in recent times is the production of orthophotographs. In a line map it is difficult to present anywhere near the detail found in an aerial photograph. As a working plan many earth scientists find the rich detail of aerial photography of special advantage. When he begins to measure, however, he quickly finds the differential scale relations intolerable. The first correction the photogrammetrist can offer is to correct the scale errors produced by camera orientation. Rectification of this type, however, in a plane correction which will not remove the scale errors resulting from terrain relief. This latter correction requires some process of differential rectification. Methods of achieving differential rectification include zonal rectification, the division of the terrain into polyhedral surfaces, the French method of facets, the Soviet method of the reversed terrain model, and the combination of differential image rectification with stereoscopic plotting.

The combination of differential rectification directly with stereoscopic plotting provides a magnification change continuously controlled by the stereoplotter. The first suggestion of this approach came from Lacmann in 1931; however, his proposal was not instrumented. As early as 1935 Gallus-Ferber provided a typical example of what can be accomplished by equipment of this type. More recently, production instruments have been developed in America under the name of Orthophotoscope and in the Soviet Union as the Slot-Rectifier FT-Shch 1.

In equipment of this type the model is profiled in parallel strips and the image from one of the stereopairs is exposed differentially through a slit. If the model is created in a double-projection instrument, scale corrections are made by varying the projection distance according to the scale on the profile. (If an optical model, as such, does not exist, as in the stereometer-type instruments to be discussed later, then, scale and displacement are determined by a computer.) The stereoscopic profile method is employed in the Slot-Rectifier, the American Orthophotoscope, and in the Gigas-Zeiss Orthophotoscope.

T-64 Orthophotoscope

Significant changes made in the orthophotoscope developed by the U. S. Geological Survey have been summarized by Marvin B. Scher in a paper entitled, "New Developments in Orthophotography." At the Ninth Congress the cylindrical drum 1960 Orthophotoscope was described. The new T-64, shown in Figure 1, employs an inclined plane as the film supporting platform. Critical mechanical adjustments required in the drum-type instrument dictated the return to the flat platform. However, for operator viewing, comfort and convenience the platform is tilted toward the operator approximately 40 degrees from the horizontal plane.

In extending the area of coverage provided by orthophotography, the U. S. Geological Survey has produced orthophotomosaics. Scaling and orientation of the individual orthophotographs are accomplished by stereotemplet triangulation. Uniquely, the data required for the stereotemplets can be derived directly from the orthonegatives.

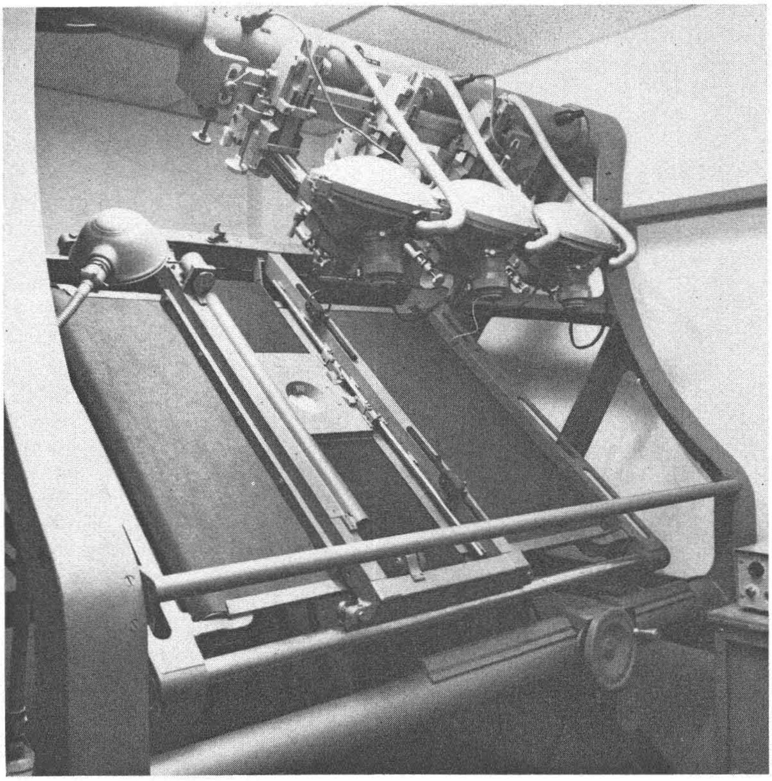


FIG. 1. The T-64 Orthophotoscope.

The U. S. Geological Survey has conducted several experiments to determine the effective mapping applications of orthophotographs and orthophotomaps. The feasibility of compiling the planimetry of an urban area from a 1:24,000-scale orthophotomosaic was established using a continuous-tone diazo rendition of the orthophotomosaic printed on a white, scribe-coated, scale-stable plastic. Planimetry on a similar diazo print of this orthophotomosaic was compiled in the field demonstrating the feasibility of combining the compilation of planimetric detail and its field review and completion. Orthophotomaps are being produced from an orthophotomosaic prepared in quadrangle map format, with a limited amount of added cartographic symbolization and marginal information, and printed in several colors by lithographic methods. Primarily only the degree of user acceptance will determine the value of this product which employs so many new and interesting techniques.

Gigas-Zeiss Orthophotoscope

One of the advantages of the Soviet Slot-Rectifier FT-Shch 1 is the application of projection apparatus with a very large depth of field and thus sharp images independent of projection distance. Recent orthophotographs of high quality have been obtained from an instrument described in "Considerations on the Design of the Gigas-Zeiss Orthophotoscope," by Dr. W. Bruchlacher and Dr. M. Ahrend, Zeiss-Aerotopograph, Oberkochen. This instrument is based on the C8 Stereoplanigraph and consists of a scanner (C8) with attached drive motors, control elements and impulse generator for the Z-motion, control desk with tape punch, and a reproducing projector with a control desk and tape reader.

The use of the punched-tape record in the Gigas-Zeiss Orthophotoscope allows the profile information to be recorded during the operator-directed profile scan in the C8 Stereoplanigraph and later used to control the output in the orthoprojector. The five-channel punched tape does not contain absolute *X*, *Y* or *Z* values of individual profile points but rather stepping orders for *X*, *Y* and *Z*. For terrain of different types the length of the *Y*-step is modified by an interchangeable cam disc. The profiles are scanned in the Y-direction at a speed regulated by the operator, the instrument automatically indexes in X, but the Z-corrections are introduced by the operator with the right-hand wheel and transmitted to the tape punch through the impulse generator.

The orthoprojector, which projects the imagery, is a photocarrier of the same type as used for model scanning in the C8. This unit is shown in Figure 2. The complete analogy between the scanner and the projector permits optimum imagery as well as transfer of setting values. Moreover, the instrument can be oriented to preplotted control points, so that rectification or a check of orientation can be made independently of the readout desk.

New Methods of Differential Rectification

The two methods of differential rectification mentioned above can only be employed with specific plotting equipment. They yield exact results only when operating with congruent bundles of rays. Thus, for every new focal-length a special projector must be used. Drobyshev proposed using the Stereograph SD with auxiliary equipment for differential rectification. The affine transformation would avoid dependence on a particular focal-length. Nonetheless, even in this proposal differential rectification is possible only in

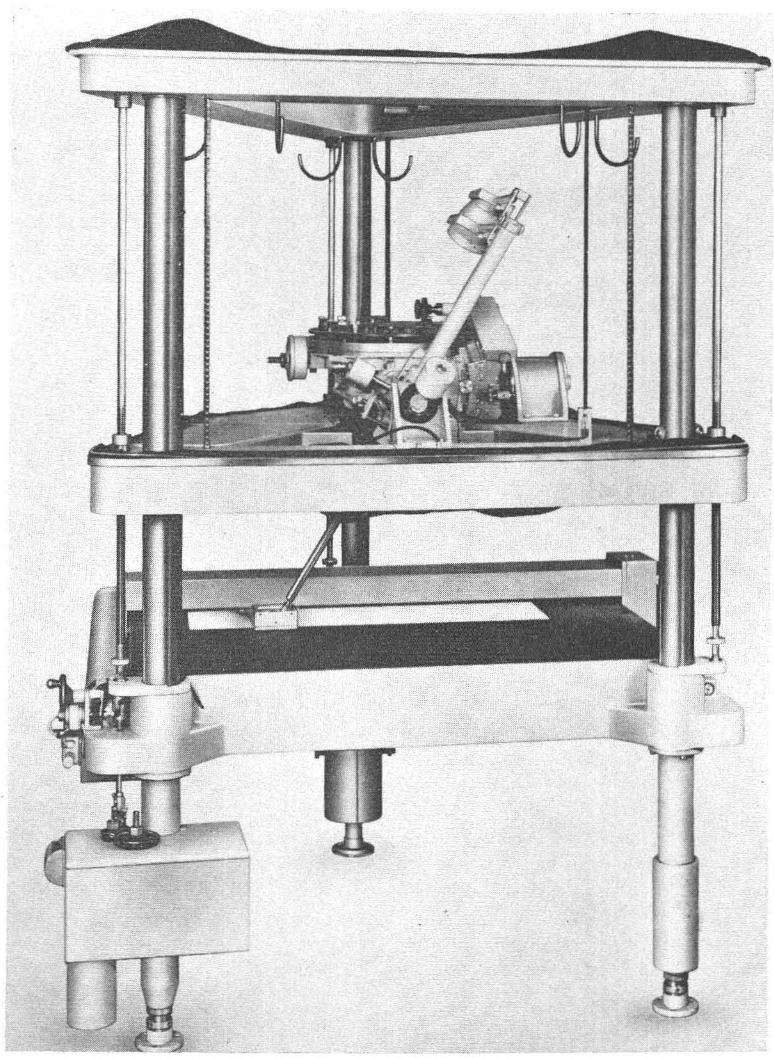


Fig. 2. The Gigas-Zeiss Orthoprojector.

connection with a particular stereoplotter, because the design of the differential rectification equipment or the settings for differential rectification are determined by the stereoplotter to be employed. Dr. Otto Weibrecht of Carl Zeiss, Jena, has made new proposals to rectify differentially using a conventional rectifier with integral automatic magnification control. His general proposal offers the advantage that the instrument can be employed with a variety of stereoplotters; that it can be used with photography of any focal-length; and further, that it can also be used as normal, plane rectifier.

If a conventional rectifier is to be employed for differential rectification, as discussed previously, it must have an enlargement dependent on terrain relief and an adjustable slit which can be moved strip-wise over the projection table with the aid of a cross-slide system. An additional special accommodation is an automatic movement of the vanishing point corresponding to perspective conditions. The necessity of coupling the differential rectifier with a stereoplotter also requires the determination of continuously variable setting values for the rectifier based on the orientation of the stereopair in the plotter. Dr. Weibrecht derives and discusses the setting values for the differential rectifier in his paper, "A New Technique of Differential Rectification."

In a second paper, "A New Solution of Differential Rectification Using the Analytical Plotters" Dr. Weibrecht considers the employment of universal stereoplotting equipment, and in particular the Helava Analytical Plotter, in conjunction with conventional rectifiers. The analytical plotter seems particularly well suited for such a combination since no special attachments are required for the conventional rectifier except slit-width control. Calculation of the constants as well as continuously variable setting values could easily be done in the computers associated with the plotter. Particular consideration is given to the coupling of the analytical plotters to the Zeiss Rectifiers SEG I and SEG V as well as a proposed non-tilting lens rectifier with two axes of tilt and an image carrier which may be swung. For purposes of differential rectification the analytical plotter offers the obvious advantage that magnification control can be handled in the plotter's computer.

Magnification control is also available in the automatic mapping equipment to be discussed later in this paper. In many of these instruments an orthophotograph is produced as the result of electronic scanning and electronic presentation, wherein magnification control is more easily accomplished. Differential rectification plays an important role in the automation of mapping.

B8-Stereomat

At the Ninth Congress G. L. Hobrough presented information on an instrument that demonstrated that automatic correlation of stereopairs had been achieved in principle. The instument, which achieved automatic correlation of stereopairs, was known as the Stereomat. Since that time there has been a Stereomat II, which was coupled to a Nistri Photomapper, but otherwise similar to the original instrument; and a Stereomat III, which employed dual scanning-tubes to overcome terrain-slope limitations. Further development of the Stereomat system has been carried out by Huntec and Wild Heerbrugg, Ltd., in conjunction with the Wild B8 Aviograph. "Constructional Features of the B8 Stereomat," by Dr. Wilfried Loescher, Wild Heerbrugg, describes this development from the point of view of the designer of photogrammetric instruments. He discusses the principal considerations in adapting the Stereomat to photogrammetric plotters. A supplementary report, "Automation Characteristics of the Stereomat B8," is presented by R. M. De Graaf, Huntec, Toronto, who has carried on the electronic development of the Stereomat.

Although some users of photogrammetric instruments looked for the development of a Stereomat package which could be added to any plotter, the designers were convinced than an entirely new instrument would have to be constructed to make maximum use of the Stereomat potential. However, since the basis for new instrument design was not available, it was decided to adapt it to the plotter which would maximize its potential and minimize its difficulties. The principal difficulties were a low signal-to-noise ratio, a terrain-slope limitation, and slow mechanical response due to the inertia of the carriage system. The Wild B8 was chosen because it could be adapted to a stereomodel scale only double the photo-scale with apertures limited only by the law of optics, thus maximizing the signal-to-noise ratio; because the mechanical principle permitted the use of separate scanning optics for the two pictures, thus overcoming the slope limitation by use of dual scanning tubes; and because the free movement of the tracing table minimized the inertia to be overcome in the scanning carriage. In the B8-Stereomat, shown in Figure 3, the projectors were redesigned so that the space rods guide the diapositives (which are lighter than the scanning system) while the optical and electronic parts of the scanning system are stationary. The CRT assembly details are shown in Figure 4. Although the measuring accuracy of the instrument suffers by moving the diapositives, the mechanical response is increased and complete freedom is allowed in the design of the scanning system.

The B8-Stereomat, unlike any of the previous Stereomats, has been equipped with a device to produce orthophotographs. This is possible in this instrument because the large optical aperture has greatly improved the signal-to-noise ratio over previous models. To produce the orthophotograph the model is profiled as discussed above in differential rectification. Here however, the area scanned is transmitted by electrical signal and produced on the screen of a third cathode ray tube which prints the orthophotograph. The amplitude of the current from one to the two scanners controls the intensity of the beam and thus the recorded photographic image. The scale of the image is charged electronically as a function of the instantaneous height of the space rod intersection. Since the scanning tube spot is imaged at reduced scale on the diapositive and the area scanned is small, the resolution of the televised image on the printing tube can be increased to avoid loss of detail.

The operational modes of the B8-Stereomat are manual, X-profile, orthophoto printing mode (X-profile), Y-profile, contouring mode and automatic orientation. In the manual mode the space-rod carriage can be moved freely by the operator. In the X-profile mode the Z-transport is driven to zero by the X-parallax, while the space-rod carriage is driven in the X-direction and stepped in the Y-direction. The tracing speed is controlled by the correlation signal. The X-profile mode is used to obtain an orthophoto print. The Y-profile mode is identical to the X-profile mode with the X- and Y-drives interchanged. In the contouring mode the space-rod carriage is driven in the X- and Y-direction to null the X-parallax with the Z-drive unchanged. The nulling operation is performed along the gradient and the trace velocity along the contour is proportional to the correlation. The automatic orientation mode is used to relatively orient two plates. After the Y-parallax in the Kappa stations are zeroed, the space-rod carriage moves through a programmed sequence of orientation stations removing Y-parallax at each by the appropriate motion. The Z-carriage is used to remove X-parallax at each station. Again, the speed of operation is determined by the correlation signal. With the model and orthophoto scale of from 1.4 to 2, the average speed of profiling is 7 mm per second. Orthophoto prints

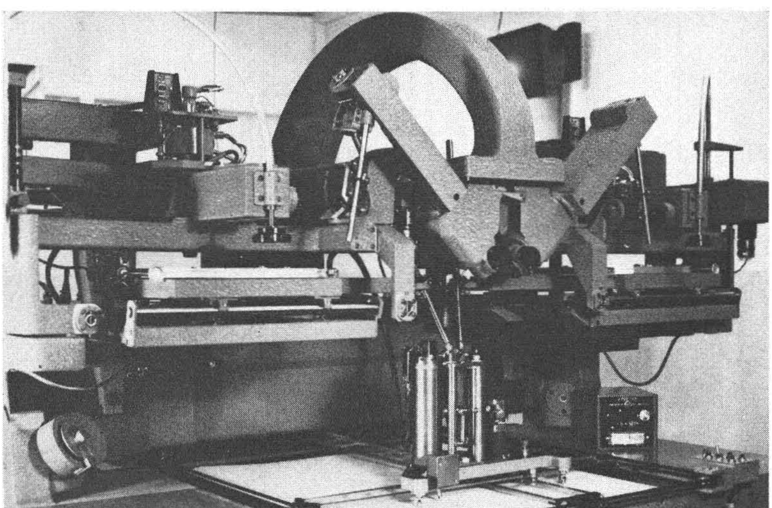


FIG. 3. B8-Stereomat.

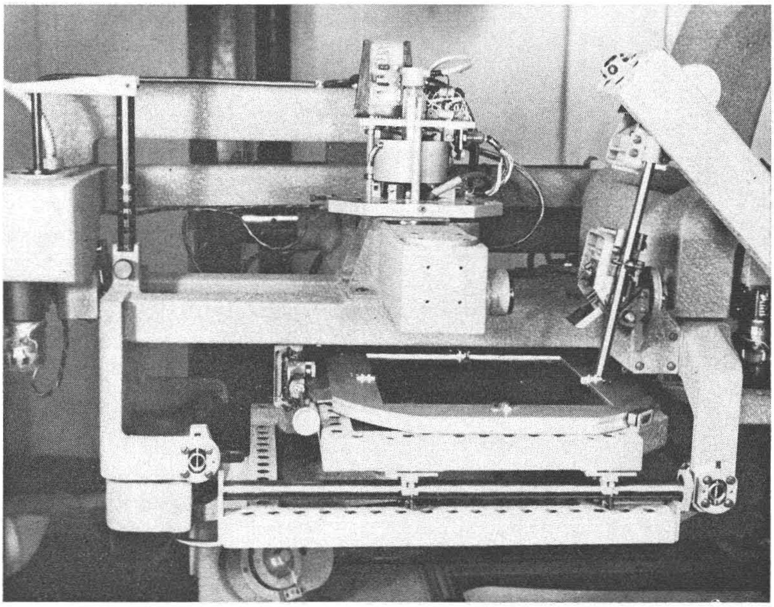


FIG. 4. CRT assembly on the B8-Stereomat.

have been obtained in approximately 1½ to 2 hours, while the average time for an automatic relative orientation is from 3½ to 4½ minutes.

Analytical Plotters

The concepts of the analytical plotter were presented at the Ninth Congress. There are now three models in this group, the AP-1, the AP-2, and the AP-C (not including the prototype AP-1C), all built by OMI and the Bendix Corporation. The first two were constructed to U. S. Air Force specifications; the latter was developed to provide the advantages of the analytical principle to users of the more common commercial types of aerial photography. The design characteristics of the family of analytical plotters were thoroughly discussed during the Second International Photogrammetric Conference in Ottawa, Canada, in 1963.

The major components of an analytical plotter are the stereometer, the computer, and the coordinatograph. An operator views a stereopair through the binoculars of the stereometer and controls the location of a floating mark in the stereomodel by means of two handwheels and a footwheel. The computer receives data from the handwheels and footwheel defining the coordinates of the reference mark and transmits servo commands to the photo carriage in the stereometer so as to position both photographs continuously in their proper position. The computer also controls the operation of the coordinatograph.

In a recent paper, "Operational Result Using the AP-C Instrument," U. K. Helava, National Research Council, Canada, reported on limited tests conducted on that instrument. These tests showed that the AP-C Plotter is accurate and capable of producing results of the highest quality; that complete and precise orientation can be performed in 30 minutes or less; and that human factors have been adequately covered.

A second paper related to this instrument has been presented by V. C. Kamm and A. E. Whiteside of the Bendix Corporation, "General Mapping and Surveying Applications of the AP-C Computer." This paper describes the general characteristics of the computer and operations which the AP-C either has or can be programmed to perform. The computer is several times faster than most medium-scale computers in current use and has the same computational capabilities, memory size, and variety of operations of computers in its class.

The standard AP-C programs include those supplied to permit operation of the system. In addition there are other programs provided which can be used for other purposes; a straight-line distance routine, a punch coordinate routine, and an X-Y plotter program. Possible extensions of these standard programs are a path-length routine and area-measuring routines. Possible new programs would include a complete analytical aerial triangulation system, cut and fill calculations, structural design problems, reduction and checking of ground-survey data, and the conversion of coordinates. The full versatility of the AP-C is still to be realized.

Turning from the commercial to the military version of the analytical plotter (the AP-2 is shown in Figure 5), a proposal for the automation of the stereoimage correlation function in the AP-2 has been advanced, "Image Correlation System for Analytical Stereoplotters," by Dr. E. C. Johnson, Bendix Corporation, and A. Di Pentima, U. S. Air Force. This proposal makes full use of the versatile decision-making and control ability of the computer. To provide an automated stereomapping capability an image correlation system is being added which will include a viewing unit, scan generator, and correlation circuits. The viewing unit integrates two flying spot scanners into the standard AP-2 equipment for stereo viewing. Two cathode ray tubes scan conjugate areas on the two photographs with two photomultipliers as the light sensing devices. The scan generators produce scan patterns for each photograph and control the size and shape of the pattern by information from the computer. The scan pattern is placed in the local coordinate system for each photograph and is compensated for local terrain slope. These signals are processed in the video correlator to produce X- and Y-parallax, X- and Y-terrain slope errors, and correlation quality.

These outputs are utilized by the computer to control overall operation and thus to generate the required plotting motions. The computer, in turn, furnishes scan size commands and scan correction information to the scan generator to control the size and shape of the scan patterns. The computer and correlator form a closed loop system which optimizes the operation of the correlator by continuously computing the average terrain slope and compensating the scanning pattern.

The usual modes of operation will be provided; relative orientation, automatic profiling, and automatic contouring. However, in addition, automation of the analytical plotter will allow semi-automatic determination of interim orientation and absolute orientation. The provision of automatic stereo perception of the AP-2 will extend the capabilities of this instrument for the rapid production of contour and profile charts from many types of photography.

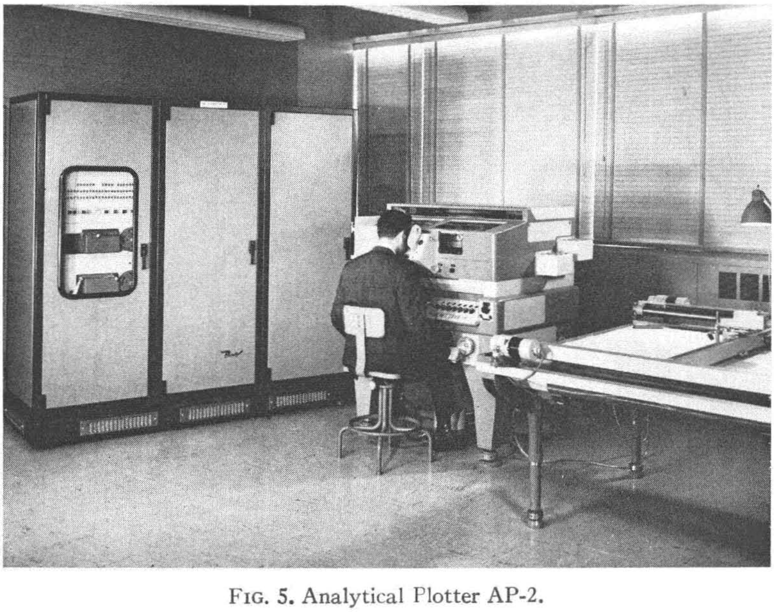


FIG. 5. Analytical Plotter AP-2.

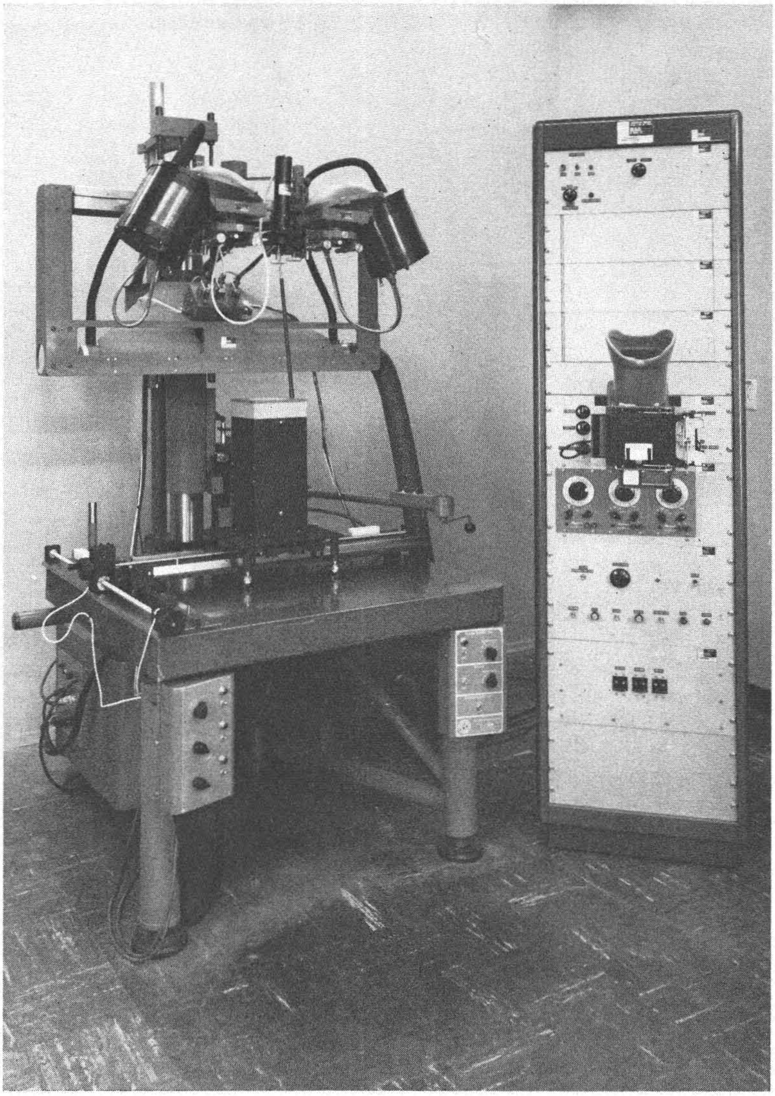


FIG. 6. Stereoplotter, Projection AP-14.

STEREOPLOTTER, PROJECTION AP-14

An automated anaglyphic plotter, which does not require a computer for its automation, is represented by the Stereoplotter, Projection AP-14 (Figure 6), described by Morris Birnbaum, General Precision, Inc. Glendale, in his paper entitled "Automatic Plotting Equipment." This instrument, which represents a novel departure from other attempts in automatic stereocompilation, utilizes a flying spot scanner table fixed in X and Y. The scanning pattern is controlled by servos and continuously senses the location and direction of contours in the model. Thus the system is not limited in its plotting speed by mechanical inertia of a scanning table, and a relatively simple, lower cost system is available.

The instrument consists of a photoscan system and a correlation system. A modified Gamble/Balplex Plotter with a photomultiplier in each projector head and a high-resolution flying spot scanner make up the photoscan system. Alignment of the scanning rasters on the two diapositives is assured by use of this single scanning source. The 12-leaf rosette scanning raster can be placed anywhere on the tube face by manual or correlator control. Differential parallax detection is enhanced by a high-frequency X-axis wobble. The correlation system senses the position of the scan pattern, height error, slope vector and information density and causes the scan pattern to locate and follow any contour that exists within the model area imaged on the scanner.

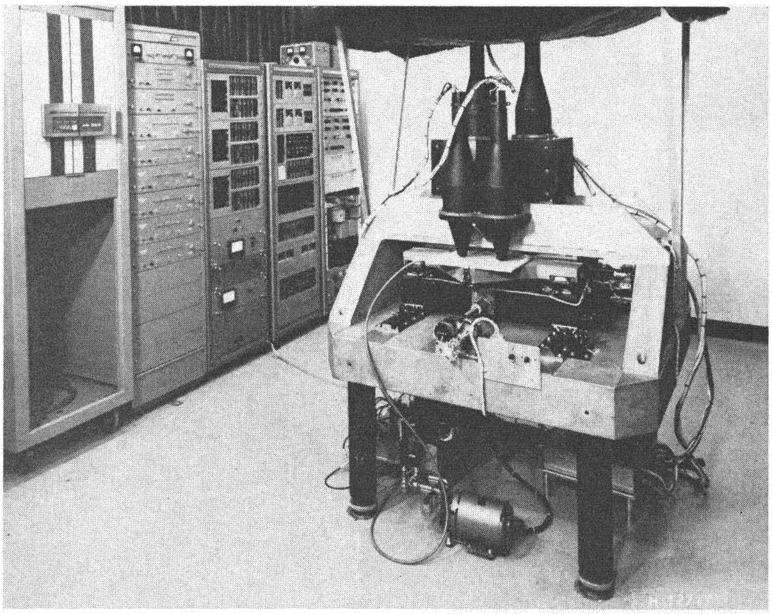
Operation of the AP-14 consists of setting the tube at a specified elevation in the model. The instrument is then in the search mode and the rosette scan performs a preprogrammed search until the cross-correlation voltage in the correlator exceeds a preset level, indicating image coincidence in the photomultiplier. At this point, when a contour is intercepted, the search mode is automatically interrupted and the contour-following mode activated. The contour is automatically traced to the edges of the tube face and the search mode is resumed until all contours at this elevation on the area of the tube face have been completed. The beam of a display cathode ray tube moves in synchronism with the DC position of the scanner beam's center and is photographed by a copy camera to produce a contour manuscript.

Contour printing speeds of from 5 to 15 inches per second and C-factors in excess of 500 have been attained in areas of moderate detail and slope. Contours are detected and traced in areas having slopes between 6 and 60 degrees. The configuration of this instrument represents a successful attempt to devise a system not limited in its plotting speed by the mechanical inertia of a tracing table. In the present instrument, the tube face covers only part of the neat model area and must be indexed to adjacent positions. To realize its full potential either sufficient resolution must be realized to reduce the stereomodel to the size of the tube face or a much larger tube face area must be constructed. Nonetheless this approach, which is basically analog utilizing electron-beam servoing techniques, does not require a computer for control and possesses the capability of contouring a stereomodel within minutes.

Universal Automatic Map Compilation Equipment

The AP-14 and the previously discussed B8-Stereomat obtain their terrain data from projected stereomodels. Another class of automatic stereocompilation instruments, as represented by the system being developed for the analytical plotter, utilizes basically a stereometer for terrain data pickup and makes all necessary corrections by means of computers. Such a system was first successfully demonstrated in the Automatic Map Compilation System, shown in Figure 7. An orthophotograph and line-drop chart produced by this system are shown in Figure 8. Based on the principles developed in that prototype equipment follow-on instruments are being constructed for production use and are described by Dr. Sidney Bertram of The Bunker-Ramo Corporation, Canoga Park, in his paper, "The Universal Automatic Map Compilation Equipment."

The Universal Automatic Map Compilation Equipment (UAMCE) consists of four identical scanning tables, a control console, a digital computer with input/output equipment and associated electronics. The equipment will serve for the automatic compilation of accurate orthophotos and altitude charts or as a precision comparator. The great flexibility realized is obtained by use of the four identical scanning tables, any one of which can be used to carry a diapositive during compilation or comparator operations or a film sheet for exposure of the orthophoto or altitude chart during compilation. Since the computer serves to center synchronous electronic scans on small conjugate areas of a stereopair of photographs, the separate scanning tables for each diapositive allow almost any geometrical relationship to exist between the imagery on the two diapositives, provided only that the basic relationships are known and programmed in the computer. The basic relationship between conjugate areas in the two diapositives is a function of the basic geometry of the sensor modified by exposure orientation, second order effects and terrain relief. If all but terrain relief are programmed in the computer, the two electronic scans will be driven to nearly conjugate positions on the diapositives; and it will be the function of the correlator to detect and determine the remaining parallax and thus the relief. The Automatic Map Compilation System was built for nearly vertical photographs. In it the two inputs and the two outputs were constrained to the same scanning table permitting only slight variations from parallel scans. However, with separate scanning tables in the UAMCE, sensor geometry is no limitation. Moreover, the system is not even limited to a point projection system and, depending on the image quality, can be used equally as well with radar presentations.



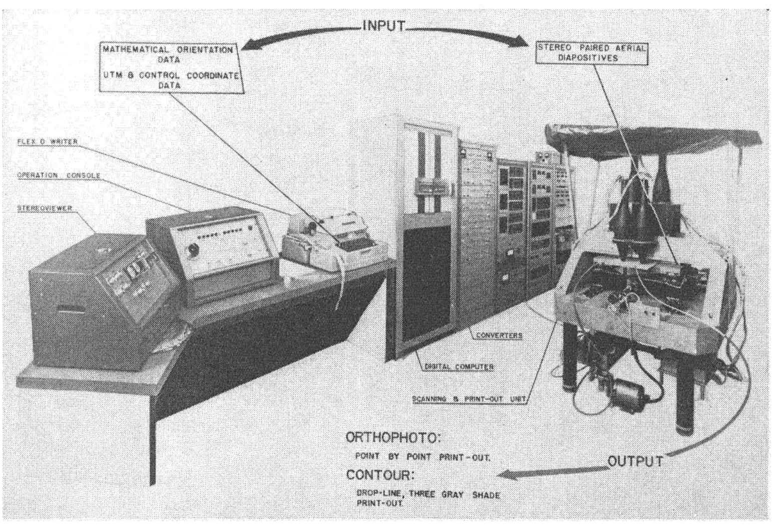
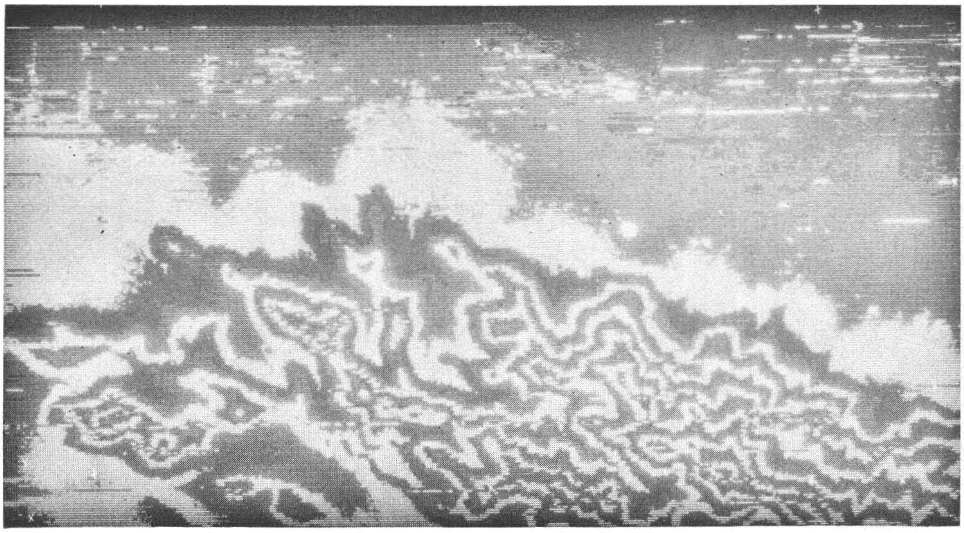


FIG. 7. Automatic map compilation system Figures A & B

The speed advantage in the UAMCE is gained by plane parallel scanning at one-to-one scale. The operation of the equipment is essentially parallel since it produces a line-drop chart and an orthophotograph as the area is scanned. The output ground coordinates are used as reference so that the scan is along a line which is straight on the map plane. As the computer centers the synchronous scans on small areas of the stereopair corresponding to a given geographic position at an estimated altitude, electronic correlators and auxiliary circuitry determine the error in height and signal the computer. The computer updates its estimate and makes an estimate for the next point in the profiling sequence. This height is the basis for the altitude chart and the video from one of the photographs produces the orthophotograph.

The UAMCE will make one hundred (100) altitude measurements per second thus permitting detailed coverage of 9-×18-inch 100 per cent overlap, 30° convergent stereo-



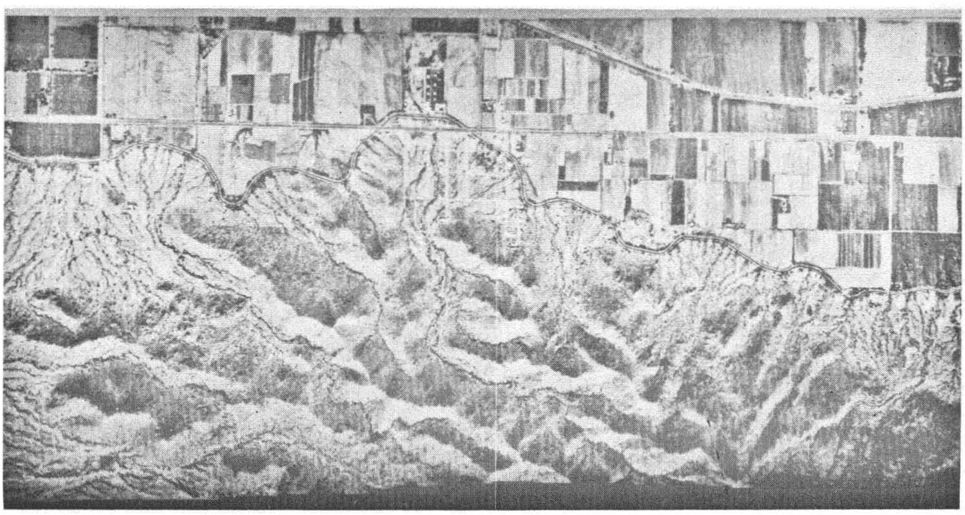


FIG. 8. Orthophotograph and line-drop chart by the automatic map compilation system.

pairs in less than three hours with an expected accuracy corresponding to a C-factor of 5,000. Smaller models and/or reduced accuracy would permit lower compilation times per model. Included in the console is an electronic stereoviewer to permit monitoring of the operation during compilation and for use during stereocomparator measurement. The general area under observation at any given time is indicated in a reference viewer by a spot of light on the print of one of the diapositives. The addition of a number of other features makes the equipment also useful as a precision comparator, in which mode it will permit virtually simultaneous stereo measurements on common areas on four diapositives. A standard error measurement of less than 4 microns is expected for such operations.

DIGITAL MAPPING

While the UAMCE operates in parallel, another system in this class operates in series. Moreover, while the UAMCE can be typified as a hybrid analog and digital system, the second is only digital. "Automatic Mapping Using Digital Techniques" by John Sharp updates the work conducted by the International Business Machines Corporation (IBM) for GIMRADA. The Digital Automatic Map

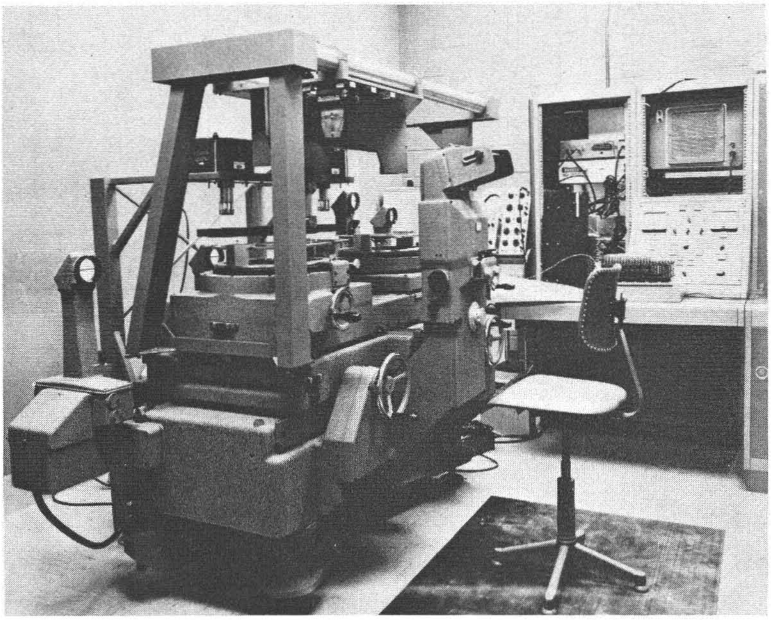


FIG. 9. Photodigitizing unit of the digital automatic map compilation system.

Compilation System has been extensively reported to the American Society of Photogrammetry. It consists of a photodigitizing unit for scanning and digitizing the overlap portion of stereo diapositives, specially written computer programs for use on an IBM 7090 Computer to perform rectification, correlation and ortho-correction on the digital photographic data, and a photomap printing unit for printing the orthophotomap with contours and grid tic information. Unlike UAMCE these operations of scanning, correlating and printing are performed sequentially; each being completed before the next is initiated. Also, it should be noted that all of the data processing is done with the terrain data in digital form; i.e., the photorectification and the image correlation.

The photodigitizer consists of a CBS line-scan tube mounted on a Wild STK-1 Stereocomparator. This assembly is shown in Figure 9. By use of a split optical system, each stereopair is scanned simultaneously in the line-scan tube and the photographic density of each element recorded on magnetic tape as a function of its position. In the present system, eight shades of gray are used. From the orientation of each photograph, the digital record of the photograph is corrected or "rectified" in the computer to produce a digital tape record of the equivalent vertical photograph. The tape records of the rectified stereopairs are now correlated in the computer to determine relative "parallax between conjugate images" or X-shift between sequences of digits in the records. Establishing the parallax for a point determines the shift to be made to form an orthophotograph, as well as the elevation data for contours. After the data processing in the computer, the orthophotograph in magnetic tape form with contour and grid tic data superimposed can be redirected through the STK-1 and line-scan tube to produce a photographic record in eight shades of gray.

Digital mapping has the potential of great versatility; since, as is the case with the analytical plotter and the UAMCE, the geometry of the sensed data presents no real limitation to its use with the system. Moreover, digital techniques also show real promise in the cartographic area as Mr. Sharp discusses in his paper, "Impact of Data Processing on Photogrammetric Instrumentation," Invited Paper No. II-5 for the Lisbon Congress.

There are two major problems in digital mapping which are receiving considerable attention, scanning and correlation. Although presently employing the line-scan tubes, IBM has developed in this application, a drum scanner/printer for use in digital cartographic systems. This unit scans and digitizes in 16 shades of gray, photographs at a spot density of one million spots per square inch over an area of 9 inches by 20 inches (a total of 720 million bits).

The matching program determines a mesh of points throughout the model which is sufficiently dense in every region to adequately establish the terrain of that region. In the digital system, the scanned spots are grouped into rectangular blocks and assigned a measure of transmissivity and a measure of contrast. Blocks are then grouped into runs, subject to the restriction that all blocks in one run must have little contrast and must have similar transmissivity. A measure of length and transmissivity is then assigned to each run. A run is viewed as a feature in the photo, such as a field, or house. The correlation technique is used to roughly identify an image and its conjugate by matching runs. Finer identification is achieved by matching blocks and, finally, spots.

Automatic Image Registration

The Itek Corporation is currently undertaking a development program leading to a complete photogrammetric system automated at key-points by automatic registration techniques. In their paper, "Automatic Image Registration," G. L. Hobrough and G. A. Wood describe an automatic registration viewer for vertical, convergent and panoramic stereograms. In this context automatic registration refers to the electronic sensing of image parallaxes and the automatic feedback adjustment of affine transformations toward registration.

The first instrument in the proposed photogrammetric program, and one which is ideally suited to describe automatic registration in general, is an automatic registration electronic stereoscope known by its acronym, ARES. ARES differs from conventional stereoscopies in that the following operations are performed automatically by electronic means; Y-parallax is reduced essentially to zero at all points in the image area; X-parallax is reduced at all points to values compatible with comfortable visual convergence, and the tonal range of the observed image and the sine wave response characteristic of the imaging system are adjusted.

ARES consists of separate, closed-TV systems for the left and right stereo channels. The enhanced and simplified images, generated in the scanning photomultipliers, are presented on the viewer. The transport system which carried the stereograms is supported on air bearings, a novel approach finding increasing application.

The electronic and automation features of ARES consist of the scanning pattern, image transformation, image correlation and image enhancement. The scanning pattern used in this device is made up of crossed-diagonal lines and is well suited both for viewing and parallax sensing. In terms of image enhancement only the regulation of tone range and a limited amount of edge enhancement have been included, although additional image enhancing features have been considered. The more important features are those of transformation and correlation.

To achieve the registration of two relatively distorted images, transformation of these images must occur. Hobrough and Wood define ten first and second order transformation errors. Together with X- and Y-parallax, they represent 12 misadjustments which must be reduced to low values for satisfactory viewing. A parallax analyzer observes the video signals from the scanned images and detects differences in timing between corresponding detail from the stereopair. The average X- and Y-parallaxes are removed by shifting the photos and the fluctuating, zero-mean, error signal represents a composite registration error signal from which the registration analyzer computes the corrections to perform the ten transformations.

The registration of photographic images is certainly basic in stereophotogrammetric operations. The automation of image registration is an important step in the development of a photogrammetric system to employ the wide scale variations which are present today.

Omnistereomeasurer BPR

Another versatile photogrammetric instrument is being developed which utilizes all types of photography for the compilation of planimetric and topographic maps. However, this instrument is primarily designed to aid in the solution of the problems which occur in the utilization of photogrammetry for highway engineering. Known as the "Omnistereomeasurer BPR" (Bureau of Public Roads), it is described in the paper "An Electronic-Photogrammetric Measuring and Mapping Instrument" by W. T. Pryor, Bureau of Public Roads, and J. H. Watson, Watson Electronics.

In this instrument two vidicon cameras are employed as the sensing elements, while a color cathode ray tube acts as the viewing screen. The digital data recording unit will record on command all elements of orientation and selected X, Y and Z coordinates. Orthophotograph production is provided by a high intensity cathode ray tube. The Omnistereomeasurer BPR will also consist of a basic measurement system, an adjusting unit, a coordinatograph, an orthophotographic unit, and digital data recording devices.

Because of the almost complete electronic handling and correction of the data, mapping, profiling or cross-sectioning may be done at any practical scale. One particular advantage of this instrument is that successive stereoscopic models can be viewed at remote locations as each model is examined. Its flexibility and expected low cost offer a real solution to many engineering problems.

Conclusions

The automatic photogrammetric instruments summarized in this paper represent only a portion of the developments since the London Congress. By the range and versatility of the instruments described, and without lengthy reference to the details contained in the individual papers referenced, it should be apparent that much ingenuity and effort have been applied to the use of automation in photogrammetry. With few exceptions most developments have been expensive and we certainly do not see final solutions at anything like a negligible cost. At the same time horizons have been extended and operations which only seemed theoretically capable of automation four years ago, have been reduced to practice.

Several trends are apparent in the automation of photogrammetric instruments; the tendency toward large and complete mapping systems, the increasing importance of numerical photogrammetry, and the increasing appreciation of human abilities of perception and logical decision. Bigger and bigger systems may well frighten the average photogrammetrist who looks for small improvements in his current operations. These im provements are coming, although not at a rate to quench our impatience. Digital computer technology moves at a pace which appears to outstrip its applications, and in the photogrammetric realm more and more operations require digital input, utilize digital data processing and output mapping data in digital form. And finally the supremacy of human capabilities of perception and decision-making is not as yet seriously challenged. The future in automatic photogrammetric instrumentation will see a flood of small improvements generated by the experience with large systems, an even greater dependence on numerical photogrammetry and the continued utilization of a human operator in those areas where he serves best.

Presented Papers

1. "The Limits of Man and Automation in Photogrammetry," Professor K. Schwidefsky, Technische Hochschule, West Germany.
2. "Drawing Tables Driven by Electronic Servos for Analogical Photogrammetric Plotters," Professor C. Trombetti, IGN, Italy.
3. "New Developments in Orthophotography," Mr. M. Scher, U. S. Geological Survey, U.S.A.
4. "Consideration on the Design of the Gigas-Zeiss Orthophotoscope," Dr. W. Bruchlacher and Dr. M. Ahrend, Zeiss-Aerotopograph, West Germany.
5. "A New Technique of Differential Rectification," Dr. O. Weibrecht, Carl Zeiss, German Democratic Republic.
6. "A New Solution of Differential Rectification Using the Analytical Plotters," Dr. O. Weibrecht, Carl Zeiss, German Democratic Republic.
7. "Constructional Features of the B8 Stereomat," Dr. W. Loescher, Wild, Switzerland.
8. "Automation Characteristics of the Stereomat B8," Mr. R. De Graaf, Huntec, Canada.
9. "Operational Results Using the AP-C Instrument," Mr. U. Helava, National Research Council, Canada.
10. "General Mapping and Surveying Applications of the AP-C Computer," Mr. V. Kamm and Mr. A. Whiteside, Bendix Research, U.S.A.
11. "Image Correlation System for Analytical Stereoplotters," Dr. E. Johnson and Mr. A. Di Pentima, Bendix Research and RADC, U.S.A.
12. "Automatic Plotting Equipment," Mr. M. Birnbaum, General Precision, U.S.A.
13. "The Universal Automatic Map Compilation Equipment," Dr. S. Bertram, Bunker-Ramo, U.S.A.
14. "Automatic Mapping Using Digital Techniques," Mr. J. Sharp, IBM, U.S.A.
15. "Automatic Image Registration," Mr. G. Hobrough and Mr. G. Wood, Itek, U.S.A.
16. "An Electronic-Photogrammetric Measuring and Mapping Instrument," Mr. W. Pryor and Mr. J. Watson, Bureau of Public Roads and Watson Electronics, U.S.A.