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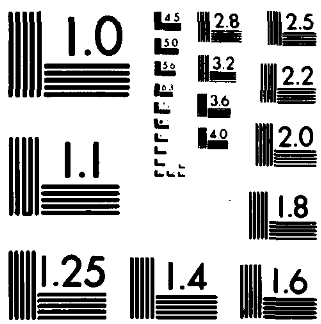

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Computer assisted stereoplotters and comparators have been in development and in use by DMA for many years. Use of this type of equipment has reached a reasonable state of maturity in the support of the DMA production programs.

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Application of this type of equipment in DMA exemplify its potential to aerial triangulation and compilation of relief and planimetry. Several of these applications are reviewed so as to emphasize the range of tasks that can be performed on computer assisted equipment given the proper software engineering.

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ANALYTICAL PHOTOGRAMMETRIC EQUIPMENT IN THE DEFENSE MAPPING AGENCY

INTRODUCTION

The transition from analog plotters to analytical plotters is clearly underway. This is not to suggest that analog plotters are obsolete, it simply means that the proportion of the stereo plotter investment that goes to analytical devices will increase in the years ahead. When the use of analytical plotters becomes greater than analog plotters is open for speculation but the use of analytical plotters is becoming sufficient to warrant a thorough examination of how they work and how to achieve their maximum potential.

A primary force in this transition is the need to have information collected, stored, and maintained in digital form. Analytical plotters are more conducive to this task than analog instruments. There are of course other reasons for the movement to analytical plotters and some of these will be discussed later.

Analytical plotters are relatively new and as with anything new, they are somewhat shrouded in mystery. This symposium and workshop will serve to remove this mystery and clearly establish the nature and potential of this class of equipment. The DMA experience with analytical plotters has convincingly shown the virtue of these devices. The purpose of this paper is to give a brief but hopefully meaningful view of analytical plotters in DMA.

Attention will be given to characteristics of DMA equipment and the essence of how the equipment is used to perform photogrammetric functions. Some remarks on trends in the use of analytical plotters in DMA will also be given, all of which should provide some appreciation of the impact of this type of equipment on the mapping community in general.

What is an Analytical Plotter

Elsewhere in this program experts will be discussing what an analytical plotter is and how it works. But there has been in recent years a considerable amount of automation applied to a range of photogrammetric devices and it may help to put these in categories. The following categories found in (1) are descriptive.

1. Analog stereoplotters interface with on-line components to provide capability for digital storage and retrieval.

2. Correlation components for the automatic matching of corresponding images in overlapping photographs and their incorporation into analog plotters.

3. Computer-controlled photogrammetric plotters with or without correlation components.

4. Totally digital systems.

DMA has two decades of experience with a variety of devices in the third category, computer controlled photogrammetric plotter,and it is in this category that the analytical plotter exists. In category 4 DMA is steadily pursuing the development of equipment, algorithms, and procedures for total digital photogrammetric operations through in-house testing, the DoD laboratories, and contractors.

The essential task of photogrammetry is to establish precisely the perspective relationships between image space and object space of metric photography. Stereo plotters allow physical reconstruction of this phenomenon in such a way that metric observations and recordings can be made of object space. Since the image-object relationships can be expressed mathematically, then a properly designed mechanism under computer control can do this task by keeping conjugate images in a viewing system for any point in model space, thus the "analytical plotter." To achieve full understanding it may be useful to remind ourselves that in practice this image-object relationship gets exercised in basically two ways, i.e., the transformation may go from image to object or vice versa.

In triangulation or control intensification we are predominately going from image space to object space and are always striving for better ways to get more accurate photo coordinates. In compilation of contours, profiles, and planimetry the reverse is true. We are predominately going from object space coordinates to image space coordinates.

In the DMA inventory of equipment there are computer assisted photogrammetric comparators and plotters. The former are used to collect and refine photo coordinates for triangulation and point positioning. The latter are used to compile contours, profiles, and planimetry. Photogrammetrically, they are equivalent in that each maintains the image-object or model-photo relationship by means of a computer. In other words, an analytical photogrammetric device can easily be a comparator or a plotter depending on the controlling computer software. Certain features may enhance the capacity to perform in either mode, but the ability to perform either function is substantially inherent in the concept of the analytical plotter. So perhaps a more general term than "analytical plotter," could be "analytical photogrammetric equipment," where subclasses are comparators, plotters, or rectifiers, depending on their primary intended use. Because, after all, we are simply extracting information from perspective images (photographs) and, if the information desired is metric in nature, then there are fundamental relationships that must be employed in all cases.

Evolution of Analytical Photogrammetric Equipment

Analog plotters are devices that, in various ways, optically and mechanically reconstruct a rendition of the camera interior and exterior geometry as well as the objects being observed. Many are built to such tolerances that the reconstruction is very accurate and the products from them can meet very high standards. While one has to admire these devices and what can be done with them, the fact is that today there are better ways to accomplish the same task. As we know these mechanical and optical representations can also be expressed mathematically and, if numerical evaluations of these mathematical expressions can occur fast enough and result in simple but accurrate linear motion, then alternatives truly exists. Modern computers have given us alternatives, and the evolution of photogrammetric devices is moving rapidly.

Development of computer assisted devices has progressed immediately behind the advances in computing hardware, measuring mechanisms, and associated electronics. These modern technological advances have made possible a diversity of design in analytical photogrammetric equipment equal to or greater than what we have seen in analog devices. But in spite of all these innovations the intent is still to extract information from photographs. Although the innovations may make operations easier or tailor a particular machine to a certain environment or purpose, the performance of the basic photogrammetric functions are at the heart of the design.

The impact of technological advances on the analytical plotter is manifested in at least four ways.

(1) reduced cost

(2) improved reliability

(3) increased flexibility

(4) peripherial features

The first two of these factors are key to wide spread use of analytical photogrammetric equipment, and judging from the number of vendors presently in the market one could conclude that some thresholds on cost and reliability have been passed. While DMA has been using analytical photogrammetric equipment for two decades, it has required large investments and a sizable corps of technicians to maintain these sophisticated devices. DMA, through DoD laboratories and contractors, developed analytical photogrammetric devices to perform tasks that were of high priority and critical to our national defense. These tasks were not only large in scope but many simply could not have been done with classical analog equipment. Now the marvels of modern electronics are having an effect on photogrammetry, as they have in so many other areas, by causing significant reductions in equipment cost accompanied by reduced maintenance requirements. Reduced cost and improved reliability thus are making analytical plotters feasible for a large number of mapping operations. Flexibility is achieved primarily by means of modern mini-computers, which are fast and powerful and operate on programs that are for the most part written in high level languages. The result is that users of this equipment can do a considerable amount of adaption to particular problems and requirements that arise within their organizations. A little later we will look at some examples of problems that DMA has solved which prove the adaptability of analytical devices. Automation in photogrammetric equipment also has lead to flexibility from a logistical point of view in that equipment can be smaller and lighter, particularly if there can be some tradeoffs in the inherent accuracy of the device.

Two classes of peripheral devices that have added and will continue to add considerable power to analytical photogrammetric equipment are mass storage media and computer graphic devices. The first of course is essential for effective operations where the output is all digital and the latter will have its bearing primarily in editing functions(2). Another peripheral feature made possible by modern computers is linking instruments together for communication and data movement to and from central processors (3)(4). Data links have been used extensively in the Integreted Photogrammetric Instrumention Network (IPIN) design in the DMA Aerospace Center (5).

Perhaps a negative impact of the rapidly advancing technology is that obsolescence may seem to come quicker. Of course, when an investment is made, the current state of technology is frozen and the hope is that the benefits derived will be viable for the owner for a long time. On this point it can be stated that DMA currently has equipment it bought in the early to mid sixties in full time productive use. There has been refurbishment and many software changes, but the major investment is still intact and productive.

DMA Analytical Photogrammetric Equipment

There is an assortment of computer assisted devices in the DMA inventory that performs basic photogrammetric functions of mensuration, compilation and rectification. To examine this inventory of equipment against these functions is complicated by the fact that often a given instrument cannot be associated uniquely to one function. For example the AS11B-1 at the Aerospace Center was built to compile contours and profiles but it has served as a comparator to measure and derive precise coordinates of ground points. This really points out the versatility of this class of equipment given the necessary engineering of software and procedures.

To pursue the discussion of the DMA experience with analytical photogrammetric equipment a brief summary of the characteristics of major devices follows.

AS-11AM. This is a two stage stereoplotter with 9x9 inch stages which has been recently upgraded with a new computer. Motion is by independent X-Y leadscrews, (one moves the stage in Y and the other moves the optics in X), with rotary encoders giving a least count of one micrometer and an overall calibrated stage accuracy of 8 μm RMS. One turn of either leadscrew moves the stage one millimeter. Motion in model space is by two handwheels and one footwheel where one turn of either produces 1 millimeter of either X, Y or Z movement in model space. This latter condition is software dependent as is the correspondence between stereo model axes and operator control wheels. An optical system providing a magnification range of the stereo model of 5X to 52X with a resolution of about 60 l/mm and a field of view of 28 mm at 14X. A panel of pushbuttons and coordinate display complete the major components of the stereo instrument.

Linked to the stereo instrument is a control computer. It is a MODCOMP II/25 minicomputer with 40K-16 bit words memory and a 800ns memory cycle time. Also serving the instrument are two removable disk cartridges containing 1.2 million words each and an alpha numeric terminal. Attached to the system is a coordinatograph which is being used as an editing tool by drawing profile as they are collected. We plan on replacing the coordinatographs with CRTs.

AS-11B-1M. The description for the AS-11AM applies to this instrument. Exceptions consist mostly of added features. Viewing optics of the AS-11B-1M are slightly different from the AS-11AM and stage size has been increased to 9x18 inches. The axis that lies in the direction of flight is software determined. The magnification range is 7-63X with resolution of 75 l/mm at 10X. In addition to an increase in stage size, necessary hardware is provided to do electronic correlation of conjugate images for the measurement of x-parallax. With this correlation equipment the AS-11B-1M can operate in either the so called automatic mode or the manual mode. In the automatic mode the instrument can collect contours or profiles with a minimum operator interaction after the process is set in motion. But when image quality is poor the automatic mode is not practical. As the Aerospace Center is currently equipped, most automatic correlation is done on the ACE (described later). Because of the speed of the ACE, the production arrangement is to use the AS-11AM and AS-11B-1M for setup and fill-in functions.

UNAMACE. This instrument contains modules which can function for scanning input diapositives and outputting profiles in digital form. The viewing system is a CRT device that provides stereoviewing for setup plus a reference viewer that gives a large field of view. Analytical relative and absolute oreientations are performed with the aid of the online computer. The hardware and software of this instrument have been tailored for an output of digital terrain elevation data as the primary product. It scans a stereo model in parallel profiles and determines elevation via electronic correlation of conjugate images, requiring assistance only in clouded, open water, or poor image areas. The UNAMACE can collect up to 100 elevations per second with 50 elevations being typical. Given a 0.3 millimeter interval at photo scale for example, a 4.5 X 9 inch model could be compiled in 1.5 hours.

ACE. This instrument is built around an AS-11B-1M chassis and incorporate some advanced techniques of stereo correlation which have yielded a high compilation speed. Compilation of a 4.5x9 inch model can be done in 0.5 hours. The output is an array of model elevations along epipolar lines with the interval between lines of 0.3 millimeters. This interval can be doubled or reduced by half, on option. The design incorporates a laser scanner to measure optical densities of the stereo diapositives which are converted to digital values. Correlation of conjugate imagery and the measurement of parallax is then done digitally. It is done in a swath like manner where the swath direction is in the model y-direction. When correlation drops below a designated threshold no elevations are output.

TA3PM. This is a three stage comparator with independent X-Y leadscrews, (one moves the stage in Y, and the other moves the optic in X). Stage size is 9x9 inches and one turn of the leadscrew causes one millimeter of motion. The least count is 1 micrometer with an overall calibrated stage accuracy of 4 μm RMS. Its viewing system provides a magnification range of 7X to 31X and a resolution of 65-100 lines per millimeter. The field of view is about 16mm in the lower range of magnification. Optical switching is built into the viewing system so that conjugate images on any two of the three stages can be viewed. The operator controls for this instrument are similar to those of the AS-11AM and AS-11B-1M. The computing and storage components of the TA3PM are identical to those of the AS-11AM and AS-11B-1M.

TA3P1. The TA3P1 is a three stage computer assisted comparator similar to the TA3PM except that the stage size is 9x18 inches and the viewing optics are improved allowing magnification up to 63X and yielding an axiel resolution of 160 l/mm. The control computer is a PDP-15/20 with 32K 18 bit word memory. Peripherals include a paper tape reader/punch, two DEC tapes, two magnetic tape stations, 10 mega word disk pack, a Tektronix 4010 display, an ASR 35 teletype, and an IBM 526 card punch. Extensive work on the refinement of mensuration methods has been performed on this device (6).

ARME (Automatic Reseau Measuring Equipment). This device is a computer assisted mono-comparator for measuring symmetrical or near symmetrical photo images. It is designed to center on the images of fiducials, reseau grid intersections, star images, and artificially marked detail points. It functions by scanning and digitizing a regular array around a target image and locates the center of the image with correlation algorithms that know apriori the type of image being measured. The raster size is about 0.8 micrometer in a square window of 200 micrometers on a side. When all images to be measured can be approximated in simple two dimensional geometric terms, the ARME is a very effective collector of precise coordinates.

Application of Analytical Photogrammetric Equipment

The use of analytical photogrammetric equipment in DMA has had a desirable impact on speed of operation, accuracy of output, and production costs. The DMA has been able to meet its mission only through the flexibility and productive capacity of the equipment described above. While the purposes of the analytical devices are the same as their analog counterparts, the computer assistance changes the role of the operator. How much the role of the operator is changed depends to a great extent on software engineering and production schemes. Developments in DMA have to a large measure led to the shift of the tedious tasks of searching and bookkeeping to the computer and left the operator free to perform the more difficult tasks that require judgment and skill. To give some notion of how this equipment is used in DMA, a summary will follow that highlights the applications for aerial triangulation and relief compilation. Stereo comparator support of triangulation will be examined first.

Stereo Comparators. The comparators are used to collect and refine photo measurements which are subsequently used for analytical triangulation by the bundle method but they may also be used for deriving precise positions of control given that the exterior orientation of the stereo pair is known. Analytical triangulation requires accurate photo coordinates to achieve reasonable accuracy in the adjustment process, a situation where the highest practical order is desired.

The TA3P1 and TA3PM comparators have undergone considerable innovation for supporting analytical triangulation and point positioning (6). The main functional elements of the mensuration process for which techniques will be discussed are: calibration, coordinate mensuration and refinement, and coordinate editing.

These comparators are leadscrew instruments with rotational encoders, as are all other instruments under consideration here. These devices require periodic recalibration to remove the buildup of contaminants on the screws and compensate for wear (6). Calibration and certification of an instrument are done with the aid of a precision grid of known interval on glass. A calibration procedure on a computer assisted device can be done rather quickly if the software is on-line and grid coordinates are stored. With a grid plate on a stage approximately lined up with the machine axes the machine can slew to the neighborhood of grid intersections. An operator points the measuring mark to the grid intersection, presses a record button, and the machine slews to the next intersection, etc., until the measurments are complete. The observed coordinates are adjusted to their calibrated values followed by the display of residuals and statistics. If tolerances are exceeded, some remedial action is necessary, or if the observed deviations from nonlinearity and orthogonality are stable, they can be modeled and accounted for in real time as the instrument is used. The latter is practiced very little in DMA at present but is certainly a viable approach to calibration.

The DMA mensuration capability provides for the determination of accurate photo coordinates of both monoscopic and stereoscopic type points to support triangulation and point positioning. Monoscopic type of points are fiducial marks, reseau crosses or star images, the latter occuring on photos used for camera calibration. Stereoscopic type of points are the images of control and pass points occuring on overlapping photos. Part of the mensuration system is computer software that transforms the stage coordinates into photo coordinates. Programmed into this transformation is the ability to remove non-perspective conditions from the coordinates such as lens and film distortion. This refinement uses stored calibrated values of fiducial or reseau coordinates with numerical adjustment techniques that are well established. The point to be made here is that the total process is on-line and many intermediate steps that would otherwise require the attention of an operator occur automatically.

The normal photo coordinate reduction procedure is enhanced by the introduction of a technique called "Average Dove Rotation" (ADR) which reduces the personal pointing biases. Two operators pointing a comparator to a well defined point will, in general, not get the same coordinate. This phenomanon exists in both mono and stereo mensuration. Triangulation solutions that incorporate the measurements of many people can be sensitive to these personal biases so this procedure has been adopted in compensation. When an operator observes a point in both a direct and reverse manner and averages the two observations, his resultant coordinate will be more consistant with that of another operator. A reverse measurement can be made by rotating the photo 180° on the stage, but all of the DMA stereo comparators have dove prisms in the optical train for rotating the image, so the rotation is done with the prisms. The procedure is computer assisted, which also forces an operator to follow through all the steps. All the numerical processing is done automatically as is the assignment of an identification number. The ADR procedure is an integral part of the total mensuration process.

Another virtue of computer assisted comparators is the elimination of physically marking of pass or control points. The photo coordinates of a pass point are related to the fiducial or reseau system so that with proper software the comparator can recover a point on command. Pass and control points that have not been physically marked in the emulsion can be transferred to overlapping photos more accurately yielding desirable benefits in the triangulation solution.

The assistance that the computer software provides an operator keeps certain types of error to a minimum. Things such ambiguous identification of points, where two points have the same identification or conjugate images of the same point don't have the same ID, rarely occur. Outliers in redundant observations are brought to the attention of the operator, allowing them to be reobserved or purged.

After a set of photo coordinates have been developed for one pair of overlapping photos a rather strong test can then be made on-line by solving for a relative orientation of the photo pair. Residuals from this solution can show bad points or systematic trends arising from uncompensated distortions. The capacity also exists to do absolute orientation on-line to ground control coordinates, which can reveal problems before the final triangulation solution begins.

There are no revolutionary concepts in the DMA mensuration procedures. They are designed to produce an accurate and consistent set of measurements made by a large group of observers. They also take advantage of automation to achieve efficiency in handling large volumes of data.

Analytical Stereo plotters. Nearly all terrain relief compiled in DMA is collected and stored digitally in the form of regularly spaced grids of elevation data. Such arrays are commonly called "Digital Terrain Models" or DTM. Software resident on the DMA analytical plotters is tailored to the process of establishing absolutely oriented stereo models and recording model coordinates as parallax is observed throughout a model by either manual or machine correlation. The compilation process as it currently exists at the Aerospace Center will be generally described by reviewing the four functional areas of model orientation, terrain collection, off-line processing, and editing. Remarks made above about calibration apply equally to machines used for compilation.

Orientation of a stereo model requires the performance of interior and absolute orientation. Interior orientation relates stage coordinates to photo coordinates. With an analytical plotter this relationship can be non linear. Therefore, a variety of nonperspective conditions such as lens and film distortion can be compensated for in the real time model-to-photo transformation as movement in model space occurs. Factors such as lens and film distortion are most common. If distortions can be expressed numerically, then compensation can be made with proper software. Typically, a camera fiducial system allows film deformation to be measured and combined with numerical calibration of lens distortion, and is input to the real time algorithms for application in the model to photo transformation.

If an interior calibrated reseau is built into the camera, then the nonperspective conditions can be more completely removed. For such photographs the reseau is observed and adjusted to its corresponding calibrated coordinates. The adjustment is piecewise where a six parameter non-conformal fit is made to arbitrary sized segments covering each photo. The coefficients are stored and used by the real time programs. Calibrated reseau coordinates are usually adjusted so that they also compensate for lens distortion. The task of observing the reseau and doing the computation is performed on-line and is aided by the computer in a manner similar to that for instrument calibration discussed earlier. The computer routines use the reseau interval to slew to the neighborhood of a grid intersection on a pattern specified by the operator. Each reseau intersection on the photo is observed seperately and, when a photo is complete, the computer will calculate the coefficients for each segment and store them for use during compilation. These coefficients can be saved for use on subsequent setups of the model if necessary.

Prior to compilation, the exterior orientation of each photograph obtained from the triangulation phase is input to the analytical plotter. Since compilation is done in a local rectangular reference frame, the exterior orientation is transformed to this frame by routines on the plotter. It is also a DMA practice to augment the exterior orientations with ground control, also derived from the triangulation phase, to provide a basis for adjustment of index differences in parallax observations performed by different operators. This is accomplished by the operator observing the model coordinates of the control points and adjusting these via a seven parameter transformation. Transformation of the control to the model coordinate system and the seven parameter adjustment is done by routines resident in the computer. The seven parameter transformation is always small, of course, and predominately a vertical translation. The exterior orientation is modified by this adjustment to minimize the effect of inconsistencies among operators and keep data disagreements between models to a minimum. Inter-model differences are usually smoothed when the product is a graphic by graphic adjustment of contours, but this kind of solution is not possible when working in the digital domain.

Where an ample amount of control is available, absolute orientation can be determined by regression coefficients which are used in the model-to-photo transformation to compensate for non linear distortions. Control points are stereoscopically observed in the model, and routines in the computer solve for polynomial coefficients in the X, Y and Z directions where coefficients include the third power. The scheme of the real time algorithm then is to alter individual model coordinate input by the operator according to the distortion coefficients. These adjusted model coordinates are used to determine the photo coordinates of the corresponding conjugate images. The capacity to determine and use such coefficients in stereo plotting is often useful, for example, when it is necessary to use an uncalibrated camera or a sensor whose interior orientation is poorly modeled.

Collection of relief after the model is setup in an AS-11AM or AS-11B-1M is either along regularly spaced profiles or along terrain features. On the AS-11B-1M and UNAMACE the profiles are collected with the electronic correlator measuring the parallax except where conditions make machine correlation impossible or impractical. Profile collected on all plotters except the ACE are uniformly spaced in either the X or Y direction of the model reference system. Spacing of elevation readings along the profiles is nearly the same as the spacing between profiles. The spacing along profiles is not exactly constant because the output occurs as interrupts in the cyclical nature of the real time algorithms causing small deviations from uniformity. The current production scheme is such that elevations are not collected precisely on the grid of the final product but the density is approximately the same, i.e., there will exist in the collected array at least one elevation reading in every cell of the final grid.

Terrain features collection is done by an operator observing elevations along terrain specific lines in the model. Terrain specifc lines follow ridges, narrow valleys, streams, and shore lines. The horizontal spacing along the lines of collection is the same as when profiling. Geomorphological data density is somewhat arbitrary, depending on operator judgment and terrain character. It overlaps and augments the profile data in the post processing phase and assures that the shape of the terrain is reflected in the final DTM.

Data from the ACE is epipolar in the form of profiles and as such the horizontal spacing is less uniform than the profiles from all the other plotters. The density of output elevations, even though not uniform, is greater than any required final grid, so that the condition of at least one elevation per final grid cell is satisfied.

The off-line processing of the various types of collections mentioned above is basically an interpolation of the elevations at specified locations to form a uniformly spaced grid of elevations for the DTM. To cover a given region any or all of the three types of data may be present and to a degree will mix and overlap. The interpolation for an elevation in the final DTM is a weighted average of the collected elevations that occur within the immediate and adjacent four grid cells. The weight is porportional to the inverse of horizontal distance that each observed point is from the desired point. The main challenge in this post processing is the ordering of vast quantities of data. Without well developed sort routines, processing time gets out of hand so that achieving efficiency in processing routines is most necessary.

There are surface fitting algorithms that have appeared in literature and have received some attention in DMA. They functionally describe the surface from the arbitrarily spaced elevations collected so that the function can be evaluated at the desired points in the final DTM. These approaches have not yet received extensive use in DMA because it seems that each has some restriction that makes it less attractive than the simple method described above.

Editing of data that has been collected and stored in the magnetic domain of computer tapes and discs presents some problems because it cannot be readily examined for any of the typical cartographic criterion. The practice in DMA has been to make computer plots of profiles in a manner that yields the three dimensional character of the data. Flaws in the data can then be recognized and remedial action taken. This action would be to recompile and replace bad data or invoke a computer editing routine. Routines in use will do such things as smooth noisy data, interpolate holes in a matrix if the hole is only a few missing elevations, and raise or lower portions of a DTM if there appears to be systematic separation. Editing has been primarily in batch mode on a large central computer.

Computer graphics devices are beginning to have their impact on DTM editing in DMA, but software development has been necessary because the available software on the market was not tailored to the problem. Both vector and raster type of CRTs are coming into use, but more development is necessary before computer interactive editing is routinely done. The next two years should show substantial progress in computer graphic editing (2)(7).

Progress in raster methods has been to developed computer software that will create stereograms from DTMs which are imaged by writing them out in a raster fashion on a printing microdensitometer. The three dimensional surface as expressed by the DTM can then be viewed with a simple stereoscope. Problems in the data can be detected but correction is not interactive. A similar development is now available on a color CRT with anaglyph stereo viewing, with the same lack of interactive correction. This latest development allows windowing and zoom of the stereo image of the DTM. The next step is to develop on-line modification of the DTM much like an operator would touchup a graphic output of a stereo plotter. This will greatly speed up the editing process.

Summary

This discussion has attempted to highlight the essence of how analytical photogrammetric equipment has been used in DMA. Attention has been given to comparators and plotters and how they are used in triangulation and in the compilation of relief. It is forseen that compilation of planimetry and surface material categories, which is largely a manual process at present, will be automated and the resulting equipment will no doubt have the concept of an analytical plotter at the heart of its design.

It is also forseen that the interface between triangulation and compilation will receive refinement such that exterior and interior orientation will be the only data passing between the two phases. That is, intensified ground control will be relied on less or eliminated. Data editing will receive considerable attention in developments in the near future. The DMA R&D program is supporting the development of equipment that will allow the simultaneous stereo viewing of a stereo model and a DTM. This should provide the most valid editing possible since the DTM would be modified in the presence of the input stereo model. Improvements in the editing of DTM data are likely to have a bearing on the design of future analytical photogrammetric equipment whose primary function is to compile relief or planimetry. Those machines whose main function is to produce refined photocoordinates probably will not have features much different from what is seen in the TA3PM and TA3PI. The most drastic change in both mensuration and compilation will be the advent of totally digital operations.

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