PAPER NO. 6

AUTOMATION IN PHOTOGRAMMETRY

by

G. Konecny

1. Introduction

In automation human functions are being replaced by the action of devices. The impetus to automation comes from the fact that certain devices are able to perform human tasks either much faster, more conveniently or more economically. To automate the human functions of sensing, manipulation and judgment human reactions must be copied by these devices operating according to various laws of physics. The last century commences with the development of mechanical machinery to replace a number of human manipulations. The human functions of sensing and judgment operate on electronic principles and this is why a more complete automation of processes could not begin until a revolutionary development in electronics had taken place during the last two decades.

Automation can therefore be carried to various stages. In the elementary stage one human process is simply replaced by another which is faster, more accurate, more convenient or more economical. Photogrammetry is a first stage automation of the surveying or mapping process.

2. Automation of the different phases of photogrammetric plotting

A more advanced stage of automation is entered when the different phases of the photogrammetric plotting process become automated.

The various phases of photogrammetric plotting can be classified as: data input, orientation, restitution and data output. Data input entails the collection of input material such as analog information in form of photographs, and control point identification images, and of digital information, such as the co-ordinates of control points, auxiliary data about camera positions and camera attitudes, camera calibration data about interior orientation and lens distortion, and of administrative decisions, such as plotting scale, plotting limits and alternative directions for procedures of orientation and output. Orientation is classically divided into interior, relative and absolute orientation. Restitution involves the process of converting image co-ordinates of a point into model, ground, or map co-ordinates. The data output concerns the form in which the result of the photogrammetric process is to appear: digital, in the form of numerical data, or analog in form of graphical plots of contour maps, or profiles, or of photographic reproductions, such as orthophotographs and drop-line outputs.

The phases of photogrammetric plotting involve various functions, which must be performed by man or machine: selection, correlation, mensuration, calculation, recording, plotting, interpretation and translation.

Selection is required in the phases of relative and absolute orientation, and when selected point objects are to be restituted, such as boundary points in plotting or transfer points in aerial triangulation. It is very difficult to automate this function, and the progress made so far has been in the experimental stages.

The Bendix Corporation has developed a system in which transfer points are automatically selected (1). Two stereo images are scanned by two cathode ray tubes. The cross-correlation function resulting out of the intensity modulated CRT voltages is used to test for optimum point location by the following criteria:

1. Best geometrical location.
2. Best image correlation.
3. Least slope.
4. Least surface roughness.

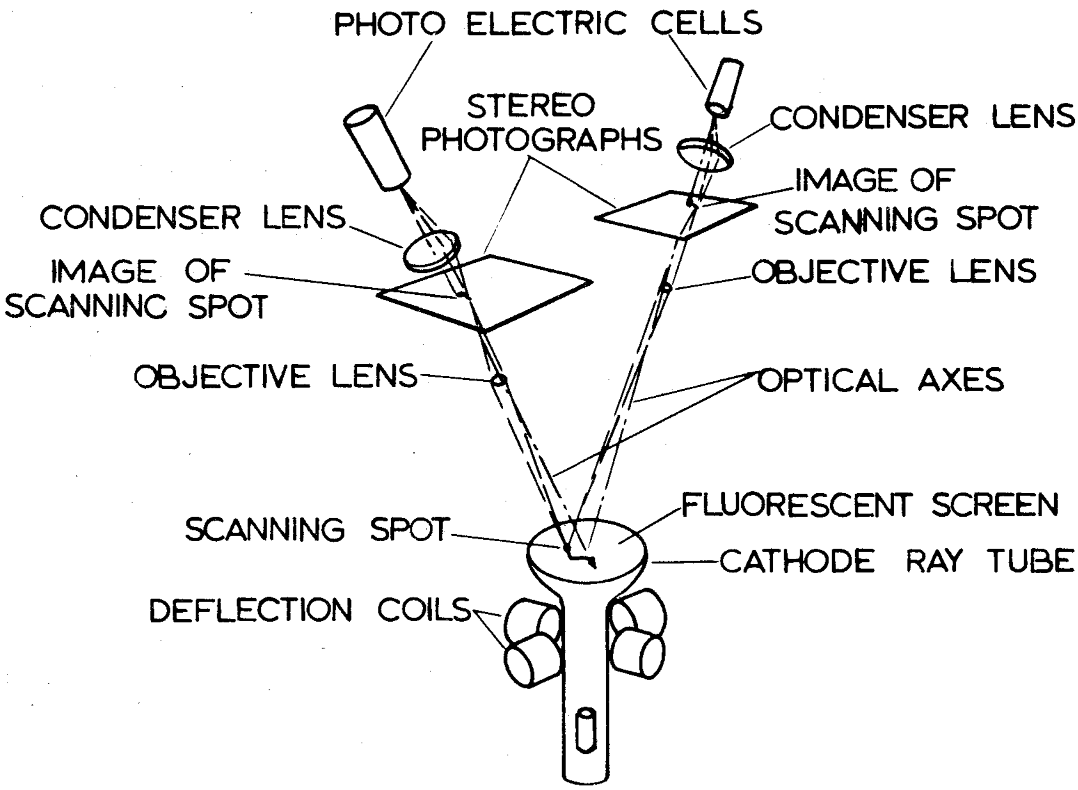

FIG. 6.1 OPTICAL SYSTEM OF STEREOMAT I AND II

The Link Division of General Precision developed an automatic point identification, marking and measuring instrument (2). A reference photo and approximate image co-ordinates are used to select and to measure images on a photographic plate. The instrument also operates on the principles of image correlation.

Star images have been selected on the basis of precalculated approximate positions by computer; their automatic centring and measurement can also be accomplished by electronic means (3).

A practical instrument for automatic point selection does not yet exist, however. The organizational activity of collecting ground co-ordinates of points will always require human selection.

Correlation is a technique to relate corresponding images. The human counterpart is stereo-perception. Automats perform the correlating function in the following way: (Figure 6.1) One or two cathode ray tubes are subjected to a regular scan pattern. The light emitted on the face of the tube is intensity modulated when passing through different parts of the two photographic images during the scan. Two photomultipliers pick up the intensity modulated light variations and transform them into time varying voltages. These voltages are fed into an electrical analog computer, the so-called correlator. The signals are filtered, differentiated, delayed and smoothed. If corresponding images are viewed the correlator output is zero. For a time lag of one of the images, as is the case for an X parallax, the correlator produces an error voltage, which can be used to control a servo-mechanism to remove the source of the discrepancy, such as the height in a stereo-plotter or a parallax in a comparator.

Automatic image correlation is faster than human correlation, but expensive circuitry or the use of an on-line real-time digital computer is necessary to scan in such a manner that correlation will not get lost. In that case the human vision, within its limitations, can act faster.

Correlation is required for the transfer of points as well as for the stereoscopic measuring and plotting process.

Mensuration involves the determination of image or model co-ordinates. Various types of analog-to-digital converters exist to obtain an automatic digital record for the co-ordinates of all selected points. Most systems in comparators and plotters operate on a lead screw principle, and rotational encoders translate rotations into digital counts. Faster devices, such as the Ferranti-Moire fringe counter, the laser-interferometer or the Bausch and Lomb DIG have not yet found use in photogrammetric instruments. It is in this area where speed and accuracy of automation can still considerably be improved.

The calculation function has traditionally been the one which was automated first. Von Gruber defined photogrammetry "as an art to avoid computations". The development of all analog stereoplotters, optical or mechanical, falls into this category. The advantage of all optical, mechanical or electrical analog computers is the immediate availability of the result. On the other hand all analogs are limited in accuracy and in the speed of moving from one calculation condition to another. Digital calculations, on the other hand, can be performed with unlimited accuracy; the development of digital computers has been so fast, that even complicated mathematical relations, such as the transformation from image to model-co-ordinates can be performed in real time, with all desired corrections for lens distortions, refraction, and the co-ordinate system in use. For point images this calculation is usually performed off-line, as in the case of analytical aerial triangulation. Analytical stereoplotters, which possess a digital computer as an integral part of the system perform the computations on-line in real-time. They offer the advantage of extreme flexibility. They have almost no limitations as far as type and conditions of photography are concerned; they even permit evaluations of aerial imagery systems such as strip or scan imagery over the range of the electromagnetic spectrum, which follow geometric laws other than those of the perspective. (Figure 6.2)

The recording function concerns the listing of image, model, or ground-co-ordinates, after these have been measured or calculated. Today all major photogrammetric instruments of the plotter - or the comparator - type can be equipped with readout devices such as a typewriter, a card punch, a tape punch, or a magnetic tape unit.

The plotting function requires plotting of points and lines. This can easily be accomplished by on-line co-ordinatographs. Automatic on-line plotting, however, has the inherent difficulty, that elevation information referring to contour identification or the altitude of a point cannot be recorded. Automatic co-ordinatographs, operating off line,

FIGURE 6.2 OMI-Bendix Analytical Plotter AP/C.

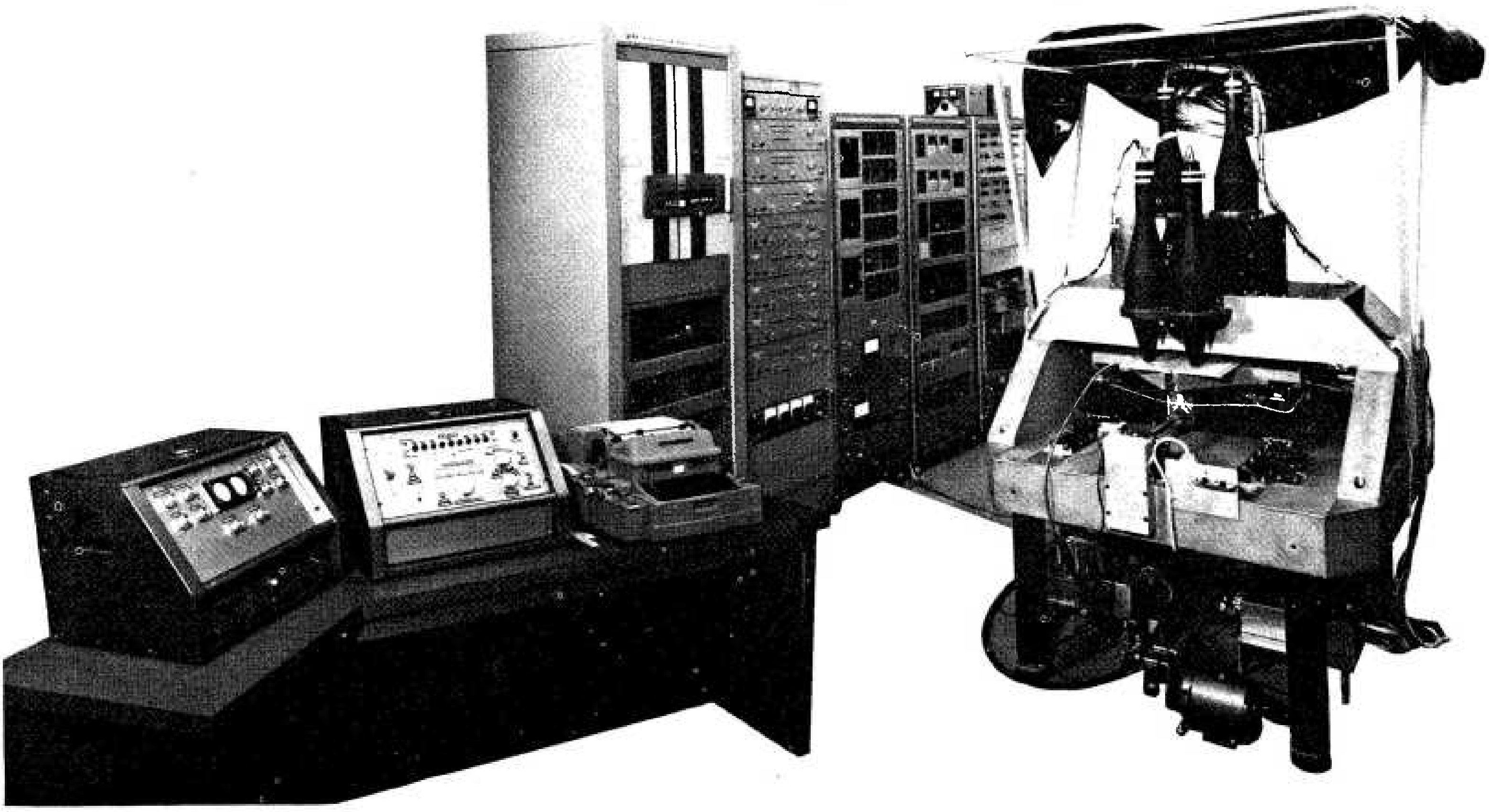

FIGURE 6.5 Automatic Map Compilation System AMCS. Developed by Bunker Ramo division of Thompson - Ramo - Wooldridge under subcontract to GIMRADA.

controlled by digital data on tape or cards, have the advantage of being able to mark points with certain symbols and to add alphanumeric information to the plot.

Most difficult to automate is the function of interpretation. In the process of plotting only a small part of the information contained in the photographs is abstracted and represented in form of a map. This abstraction involves the recognition of specific objects under varying conditions of contrast, illumination, viewing angle and scale.

A considerable effort is being put into automatic terrain type discrimination (4), (5), and into the automatic detection of objects (6), mostly for military purposes. But only elementary success has so far been achieved.

The translation function deals with the symbolization of interpreted features into the map. This problem is closely tied with the problem of identification, and no workable automatic solution exists so far.

In order to avoid the most serious difficulties connected with the automation of all phases of photogrammetric plotting, it is merely necessary to find alternate solutions for the functions of interpretation and translation. It is for this very reason, that other outputs have been sought, which permit the interpretive function to be carried out afterwards. All current automatic stereomapping systems possess an orthophoto-output, and most also produce a drop-line chart. (Figure 6.6)

For the orthophoto an overlay with all pertinent additional information and symbolic abstraction may be made on the basis of a correct geometry. To extract contours and to add elevation symbols to a drop-line chart overlay is also a simple matter. The drop-line chart must nevertheless be considered as an alternative to a contour-plan, which developed out of the difficulty to trace contours automatically; enclosed contours would repeat the contouring procedure over and over, and contouring was impossible simultaneously with the orthophoto-production.

Orthophotos have in the meantime gained widespread popularity not only as an output for the derivation of maps by cartographic techniques, but also as a substitute for planimetric maps.

A large variety of orthoprinters has been developed. These have mechanized the plotter motions and have automated the output, but they still require the correlating function of the human operator. Such systems have the advantage of a low cost and high resolution, but they are only partial solutions in the sense of automation.

Whenever it becomes possible to separate the individual functions of photogrammetric processing into separate operations a relatively simple automatic approach will be possible. This is the case for aerial triangulation: While no suitable point selection device is available to photogrammetric practice, and while automatic image correlation would be unreasonably expensive for this purpose alone, these operations can be substituted by manual selection (pricking) and transfer of points under the stereoscope or in a transfer device. The subsequent operation of mensuration and recording can be carried out in a mono- or a stereo-comparator. While the identification and selection of points is done by the operator the recording is automatically made on punch cards or punched tape. The processes of calculation and output by an on- or off-line printer, and if need be a graphical representation of the points are carried out automatically off-line and in sequence.

There is considerably room for the improvement of the automatic phase. Most formulations for analytical aerial triangulation follow the analog-instrument approach, in which model after model is formed and joined together. The strip and the block is adjusted by more or less arbitrary practical procedures, with intermediate outputs on cards used as inputs for the refining adjustments. In some cases the orientation and computation phase is still partly or completely carried out in analog instruments. This is justified, if a number of analog plotters are already available, and if they are also used for plotting purposes; but after it has been established that analytical procedures are more accurate and less costly, there is certainly no reason why first or secondary order plotters should be purchased for the main purpose of triangulation. A further improvement in accuracy and an overall saving is to be encountered by the revision of present analytical procedures. It is an established fact that computation costs per output decrease when the size of the computer increases. Most analytical programmes have been written for small computers. The logic and the data-manipulation in such programmes is wasteful in the long run. Programmes which are able to incorporate all conditions existing in a block permit a more proper treatment according to probabilistic theory; they are technically feasible in even medium sized computers of the size of the IBM 7094

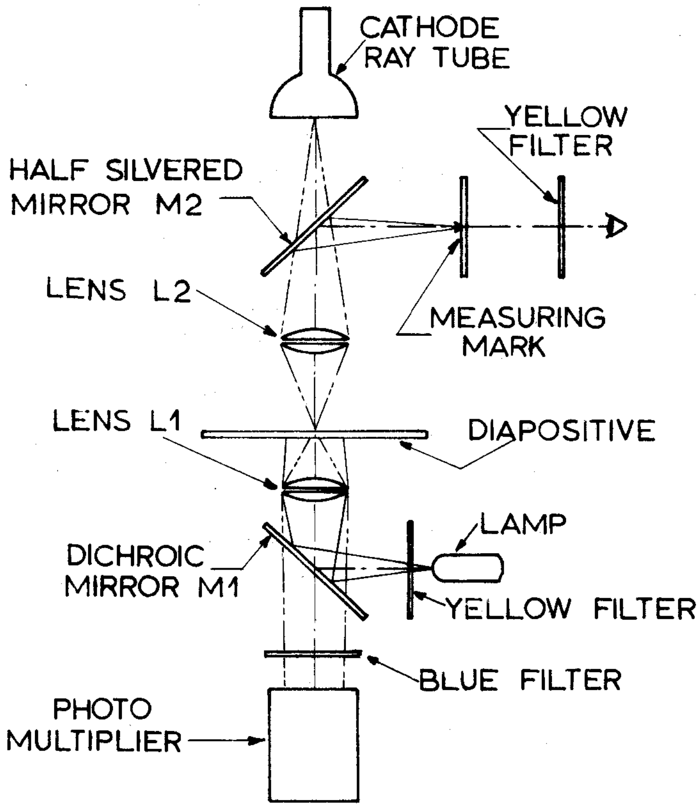

FIG. 6.3 OPTICAL SCHEME OF B-8 STEREOMAT.

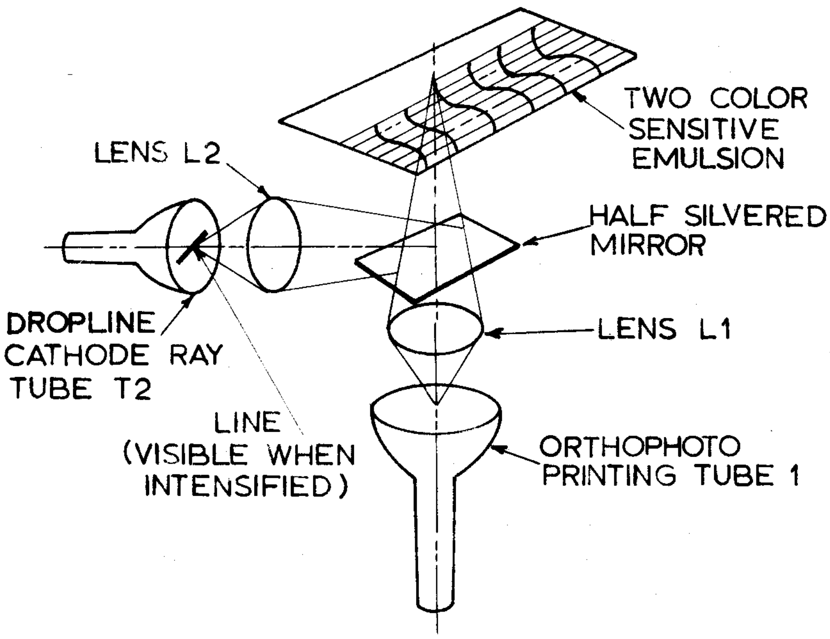

FIG. 6.4 STEREOMAT VI — SYSTEM ENABLING SIMULTANEOUS PRINTING OF ORTHO-PHOTOGRAPHY AND DROP LINE CONTOURS.

with about 30 000 words of core memory. On this computer 100 photographs can be fully triangulated and adjusted in less than 2 hours at a cost of less than $600. Larger computers should reduce this cost even further.

The programmes should be written in as general a manner as possible. While auxiliary data will provide values for exposure stations, exposure directions, or their co-ordinate and direction differences, and even heights for various terrain points, these data are not expected to be of the same or of a superior accuracy than can be expected from photogrammetric triangulation. It should therefore be possible to include auxiliary data, control points, photo-co-ordinate observations and any additional conditions (a lake has equal elevation) with appropriate weights into the adjustment. Such a programme already exists for a capacity of 100 photographs. It has been written by Raytheon/Autometric for the research agency of the U.S. Army. Another programme of even larger extent is being prepared by Dr. Schmid at the U.S. Coast and Geodetic Survey. The adjustment principle is that of observation equations with conditions.

The use of such a programme will permit the calculation of adjusted values for the orientation elements of a plotter to be used for the restitution. A careful plotter calibration may then eliminate the need for relative and absolute orientation procedures.

Returning to the problem of photogrammetric plotting, one finds that the individual functions to be performed are closely interrelated in the various phases of the process. Orientation requires selection, correlation, calculation and measurement, and the plotting of contours requires selection, correlation, calculation, measurement and plotting all at the same time. This is only possible in automated systems which are able to integrate most of the functions required. The exception remains the selection of control points and the interpretation of photographic information, which still has to be done by the operator.

3. Automatic Stereomapping Systems

All significant automatic stereomapping system developments are adequately described in the "Photogrammetric Engineering" issues of the last 10 years. Here it is only necessary to refer to the systems which have crystallized as potential production instruments.

The first in this category is the Stereomat - B8, an analog stereoplotter with automatic image correlation. It is the least expensive answer to the problem of automatic plotting. It costs about $120 000. The versatility of a digital computation has been sacrificed for the lesser expense of a simple second order analog plotter. (Figure 6.3)

It has two cathode ray tubes generating blue light in a synchronous random scan pattern while the carriage moves in X or Y direction. The photomultiplier receives the blue light, which has been intensity-modulated by the diapositive and passes it on to the correlator. The viewing of the diapositive occurs in reverse order by use of yellow light and dichroic mirrors and filters. The random scan pattern can be used to determine X- and Y-parallaxes and thus the removal of Y-parallaxes may be used in an automatic relative orientation procedure. The X parallaxes control either the Z-movement in the profiling mode, or the X - Y movement in the contouring mode, for which a special scan arrangement is used in order to automatically determine the slope of the terrain. The output consists of an orthophoto, which is produced in the profiling mode. The new Stereomat VI model also has the provision to produce a contour plot onto the orthophoto. Whenever the Z passes a predetermined contour level a second CRT produces a line perpendicular to the direction of the slope which is mirrored onto the orthophoto. (Figure 6.4)

The stereomat can evaluate a complete model in about 2 hours including automatic relative orientation and operator controlled absolute orientation. During a working day an operator is therefore able to operate several instruments of this kind at one time, or he can be engaged in other preparatory and organizational work.

A more versatile, but also more costly system is the Universal Automatic Map Compilation Equipment (UNAMACE). It developed out of the prototype of the Automatic Map Compilation System. (Figure 6.5) Both instruments were designed by the Bunker Ramo division of Thompson-Ramo-Wooldridge, Glendale, California under subcontract to GIMRADA, the U.S. Army's photogrammetric research organization. The Unamace has a cost of about $600 000.

It combines the versatility of an analytical plotter with the speed and convenience of an automatic image correlation system. It consists of 7 parts: a correlator, a digital computer, a viewer and 4 plotting tables, interchangeable in their functions. In the plotting procedure 2 tables are used to carry the diapositives; they are equipped with flying spot scanners which feed the video signals to the correlator. The digital computer contains the photo-geometry in digital form and the correlator signal is used to change the digital values of height during the scan. The scan pattern is a modified TV scan with 128 lines per area element. The analog circuitry of the correlator permits to derive X- and Y-parallaxes, as well as slopes, out of the video signals. These are used to change the scan pattern, so that corresponding images are scanned, despite the perspective representation in the photographs. For production of the orthophoto and the dropline output undeformed scan patterns are used on the two other tables. (Figure 6.6) While the Stereomat B-8 operates on a similar principle, it does not make use of the scan pattern deformations in viewing: The Unamace also feeds the undeformed scan patterns of the two diapositive table flying spot scanners into the two cathode ray tubes of the viewer. It is therefore electronically possible to produce stereo-images for any type of image geometry. The Unamace has successfully been used to evaluate radar imagery, which is impossible to view stereoscopically without electronic image deformation. The viewing possibility is of course only of secondary importance for monitoring in an automatic system, as long as correlation is achieved.

The Unamace can also successfully be used for a more automated form of aerial triangulation. For this purpose up to 4 diapositives can be placed onto the plotting tables. When interior orientation is established by a simple procedure and when approximate photo co-ordinates of a control point or of a transfer point are fed into the digital computer, the system automatically brings this approximate location into the viewer. The measuring cross can manually be set onto the control point, the 3 corresponding photographs can be automatically correlated in sequence, and their co-ordinates read out. For image transfer it is not even necessary to select a transfer point, since the correlation is automatically carried out over an area, and since the subsequent analytical triangulation will determine exposure stations and exposure directions, which can be numerically introduced on most plotters.

Analytical plotters such as the Unamace only require this type of input in digital form. If this information is substituted by control point information, orientation procedures provide the necessary parameters. But even in this phase analytical plotters are more versatile. They can solve relative and absolute orientation in one effort in form of a double resection in space or they can utilize points lying outside of the stereoscopic coverage on one photograph for a space resection of one camera and a subsequent relat ive orientation of the second photo.

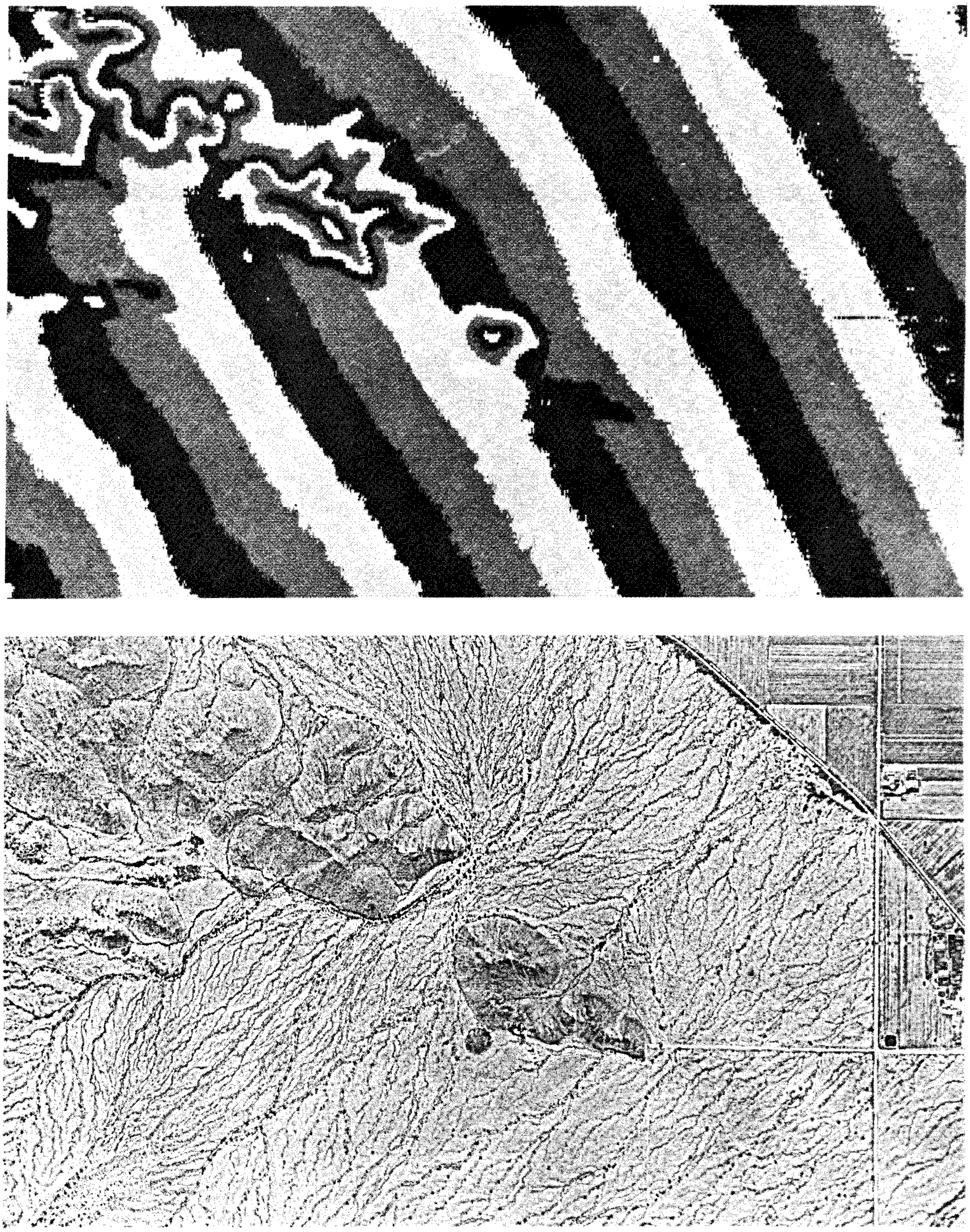

FIGURE 6.6 Drop line chart and ortho-photo compiled by UNAMACE.

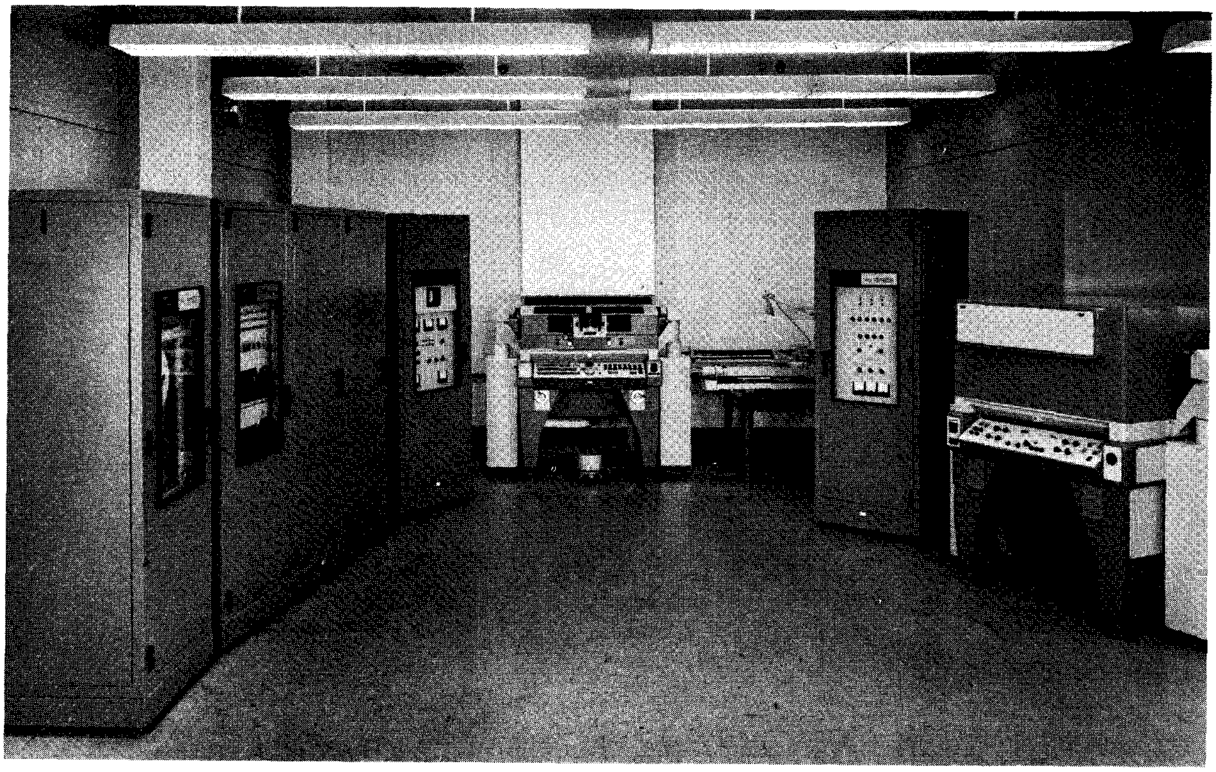

FIGURE 6.7 Automatic Analytical Plotter AS - IIC with orthophoto system. Developed by Bendix Research Laboratories in collaboration with OMI under sponsorship of U.S. Air Force Rome Air Development Centre.

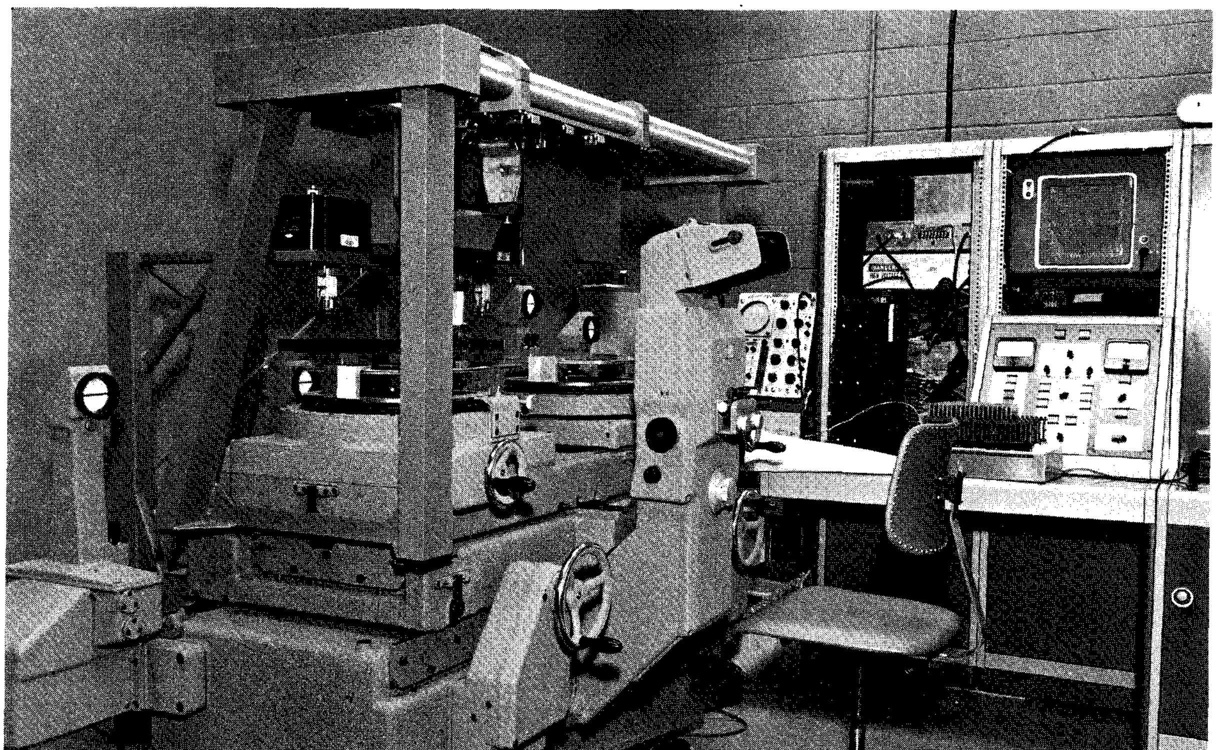

FIGURE 6.8 IBM Experimental Digital Automatic Map Compilation System based on Wild STK - 1 Stereocomparator.

The output possibilities can also be broadened in scope. While one table produces an orthophoto, the second table may be used to produce a dropline chart, or another orthophoto at a different scale, or even a new form of output: a product which in its Y - geometry corresponds to the orthophoto, but in which height differences are expressed by a parallax scale convenient for visual observation in conjunction with the orthophoto. Symbols may also be electronically inserted into the orthophoto output.

It is obvious, that the Unamace constitutes the most versatile photogrammetric plotting equipment of today.

A new automatic development for the U.S. Air Force, the Bendix - OMI Analytical Plotter AS-11-C (the automated version of the AP-2) operates on similar principles at about the same price, except that the viewing is carried out by an optical rather than an electronic system, and that the orthophoto and dropline outputs are not interchangeable with the diapositive holders as in the Unamace. (Figure 6.7)

The Bendix Corporation in Southfield, Michigan, as well as Bunker Ramo are presently engaged in the development of automatic systems on the analytical plotter principle which will be more attractive to the practical user in purchase price, but which will sacrifice some of the flexibility of the present systems.

A few other interesting developments have been carried out experimentally in the past. The Digital Automatic Map Compilation System, developed for GIMRADA proved that it is possible to digitize the information of a photograph and to continue further processing by digital computer. The digitizing equipment, which transformed a small photographic area element into one of 16 gray-scale values was attached to a Wild STK-1 stereocomparator. (Figure 6.8) The processing was done on the IBM 7094. The orthophoto was printed as a line sequence of dots with magnitudes varying according to the gray-scale values digitized. Contours were drawn digitally. The system was finally not considered to be a practical answer, because the digitization of photographic information into large resolution elements and only few gray-scale values means a drastic reduction of the information content of a photograph. (Figure 6.9)

Nevertheless, the thought offers great possibilities which can yet be developed: While correlation can best be accomplished by electronic analog procedures, it would be quite feasible to process the correlated information by digital means in a much better way than this can be done today. A relatively crude example of digital processing consists in the recording of a digital terrain model and its further processing on the digital computer, as this has been done during the evaluations of Lunar Orbiter photography by aid of the Stereomat - B8 for the output of slope maps and altitude charts.

It is only necessary to improve the input-output facilities of the digital system in order to produce an off-line digital mapping system from a tape of correlated and referenced information. In such a way the cost of automatic systems may perhaps be substantially reduced.

4. Ultimate Automation

It is ultimately possible to change the entire process of photogrammetry to produce a more complete automation of mapping techniques. While such thoughts are so far nothing more than ideas, some of these have already been expressed in great detail. Paul Rosenberg envisions a system of "electronic photogrammetry" in which the terrain information is gathered by electronic scanners (7). The digitized signals are later processed by computing techniques. Such principles are already applied for imagery systems other than in the visible or near-visible range, and when vidicon images or photographs cannot be recovered and have to be transmitted, as is the case from the Moon, Mars or Venus to earth.

It is likewise also possible to consider the evaluated digital terrain information as an end product on magnetic tape. Such a "digital map" can be stored economically and interrogated at will for the desired information in form of a visual output or a dimensioned quantity. Automation can therefore still be carried very far from its present status.

5. Conclusion

While the development of photogrammetric automation is constantly going on, the practical photogrammetrist must assess its use for present day production. This assessment must be made with the following background in mind:

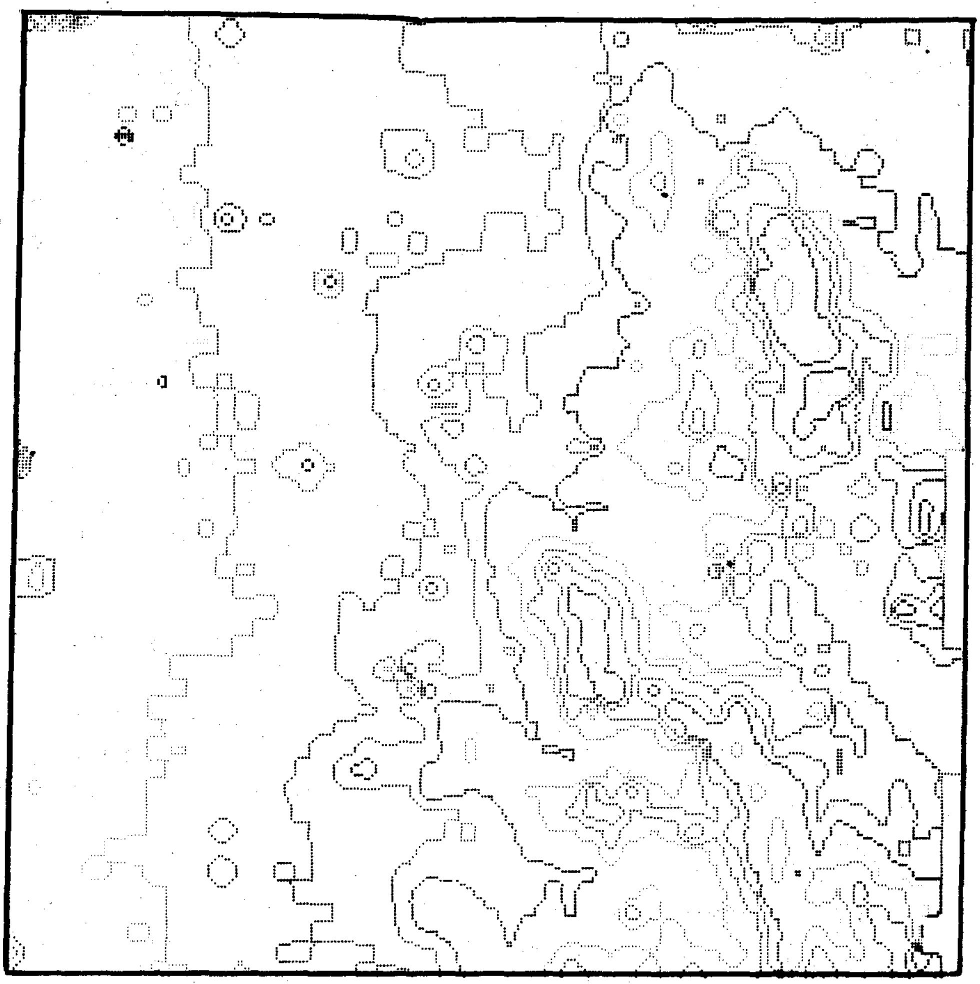

FIGURE 6.9. Contour output from IBM Digital Automatic Map Compilation System.

Figure 6B. CONTOUR MAP PRODUCED BY THE PREDICTIVE SYSTEM II

With the exception of the original Stereomat I all automatic developments were financed by U.S. defence funds. There were to enable mapping procedures of very large areas in the shortest possible time. They were to have the versatility to evaluate imagery of varying type and quality. The economic factor was of secondary importance.

On the other hand it was by these efforts that development costs could be absorbed, and photogrammetrists the world over have now the advantage of tested systems, which are capable of operating at a 10 times higher speed than the human operator.

The photogrammetrist, thinking in economic terms, is already able to justify the use of automatic systems if his work load is sufficiently high. The real importance of automatic systems will be brought about, if it can be demonstrated that automatic photogrammetry will make the mapping process as such more economical, and when consequently more mapping will be considered necessary.

Practical photogrammetry will have to assess the different systems according to equipment cost, amortization, cost and quality of labour, productivity, downtime and the environment required. Far reaching decisions in the organization of photogrammetric establishments will also be necessary, if automatic systems are to be integrated into present production.

The academic approach should be not to take a stand for or against the application of presently developed automatic systems without having had the opportunity to familiarize oneself farther and deeper with the elements of photogrammetric automation by actual contact, study, research and development so that a clearer understanding of the phenomenal photogrammetric development of the last decade becomes possible.

References:

(1) R.M. Centner and C.W. Matherly. Automatic Pass - Point Selection . Photogrammetric Engineering, 1966, pp. 834-841.

(2) E.R. Demeter. Automatic Point Identification Marking and Measuring Instrument . Photogrammetric Engineering, 1962, p. 82.

(3) J. Lentz and R. Bennet. Automatic Measurement of Star Positions . Electronics, June 1954.

(4) A. Rosenfeld. Automatic Recognition of Basic Terrain Types from Aerial Photographs . Photogrammetric Engineering, 1962.

(5) A. Goldstein and A. Rosenfeld. Optical Correlation for Terrain Type Discrimination . Photogrammetric Engineering, 1965.

(6) J. Hawkins and C. Munsey. Automatic Photo Reading . Photogrammetric Engineering, 1965.

(7) P. Rosenberg. Information Theory and Electronic Photogrammetry . Photogrammetric Engineering, 1955, p. 543.

DISCUSSION ON PAPER NO. 6.

Chairman: Major W. Child, Royal Australian Survey Corps.

CHAIRMAN: I feel that no organisation in Australia is ready for automated photogrammetric equipment at the moment. The U.S. developments are based on military requirements which do not match our normal mapping requirements. The manufacturers are not yet in a position to provide satisfactory servicing, which is very important in new electronic equipment. They are extremely expensive and their accommodation and the organisation necessary to ensure a sufficient work flow will cause problems.

J.D. LINES: I agree with most of the points made by the chairman. Nevertheless a start must be made somewhere and National Mapping is committed to the purchase of an automated plotter. The one chosen, the Wild B8-Stereomat IV will cost $125 000 plus $35 000 for the digital output, giving a total of $160 000. We intend to familiarize ourselves with the equipment and to assess the capabilities before committing ourselves further.

We have had experience of the maintenance problem, with the Aerodist equipment. However the purchase of the Stereomat equipment was negotiated to include a two-year maintenance contract.

Is the work load sufficiently high? Yes, on the 1/100 000 mapping programme there is more than sufficient mapping to keep the instrument busy. To make it pay, two shifts per day must be worked.

The problem of accommodation has been solved. The floor must be reasonably strong and the structure stable, and of course the area must be air conditioned.

D.R. HOCKING: Can the speaker give some idea of the reliability of the automated equipment, particularly the B8-Stereomat with regard to maintenance of production rate?

KONECNY: The problems encountered are mainly those of getting the digital equipment working. In my experience at NASA, a representative was on hand twice a week to deal with breakdowns and routine checks. After about six months most problems had been ironed out and the down time was insignificant.

W.B.R. SMITH: Professor v. d. Weele drew a distinction between mechanisation and automation. He defined mechanisation as that part of instrumentation which replaces human manipulations, while automation replaces human judgement with instrumental decisions.

Can the speaker indicate the extent to which digital terrain information is used for engineering (principally road) purposes in the U.S. and Canada?

KONECNY: Most highway departments in the United States use digital equipment which digitizes cross-sections. This equipment is normally attached to Balplex or Kelsh instruments. Besides the work described in the paper by IBM, now discontinued, a digitized model has been developed by the Massachusetts Institute of Technology. I do not know whether it has been tested in practice yet.

K. LEPPERT: How does the drop line method of height representation work? Must the whole of the model be scanned for one contour or are all contours determined during one scan?

KONECNY: The contours are produced in one scan in the same profiling mode as the orthophoto. Every time the scanner crosses a contour a drop line with appropriate orientation is printed.

HOCKING: When the B8-Stereomat is set for contouring, the time taken for one model is seven hours. The drop line chart plus orthophoto takes two hours.

In view of the striking quality of recent lunar photographs using video technique, can KONECNY say whether the resolution using video will approach optical resolution in the near future or what proportion, video to optical resolution, can be expected?

KONECNY: This is a problem in the field of electronics. It depends mainly on the width of the spot scanner. The best which it can achieve at present is 20 lines/mm. whereas photography has a resolution of 50 lines/mm. or better. In magnifying the photograph to produce the orthophoto, this resolution will drop further. With automation scanning is along parallel strips. The finite width of these strips causes jumps at the edges of adjacent strips, in following a particular object.