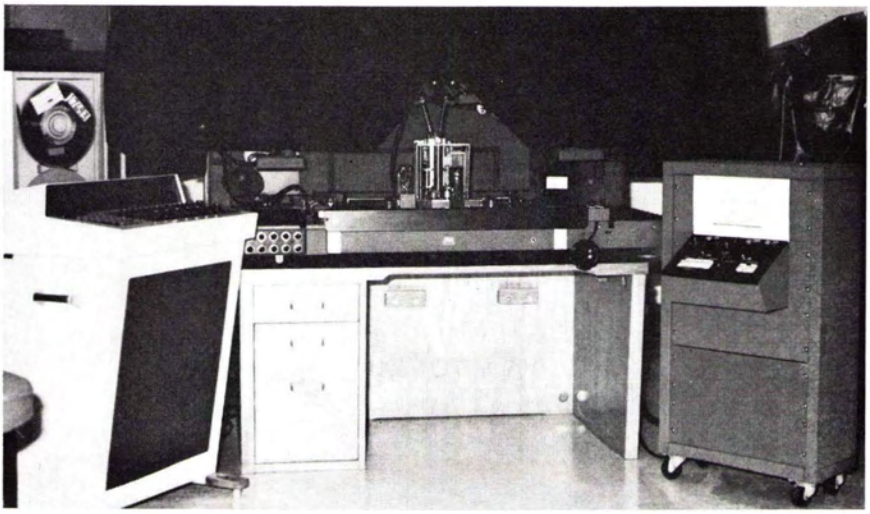

FIG. 1. Wild/Raytheon Stereomat B-8 with Autotrol Digitizer and Kennedy tape units.

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Maps from Digitized Stereomat Data

Slope and altitude charts have possible application to Lunar Orbiter data.

(*Abstract on next page*)

INTRODUCTION

THE PAST DECADE HAS brought the development of a variety of automated stereomapping instruments. While this development is still in progress a number of instruments in various price ranges have already proved themselves as production models. Of these the Stereomat B8 is presently capable of automatic contour plotting and of producing automatic orthophotographs. High-priced instruments, based on the Analytical Plotter principle, such as the UNAMACE and the AS-11-C, are now capable of correcting model deformations analytically and of printing drop line charts simultaneously with the automatic orthophoto production. To a

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limited extent, this can also be accomplished with the present Stereomat B8 if it is used in combination with a digitizing unit, such as the Autotrol digitizer with a Kennedy tape unit (see Figure 1).

While the Stereomat scans the oriented stereomodel in profiling mode, the *x*, *y*, *z*-coordinates of the correlated terrain information are stored at fixed controllable intervals on magnetic tape. The digitized information can subsequently be processed on a general purpose electronic computer. It is possible to perform absolute orientation analytically to control established by aerial triangulation or by other means. Moreover the model may be corrected for deformations in height, and an altitude chart may be compiled digitally in whichever form is most convenient. Printout of the altitude chart may be made on data plotters or directly on tape by use of a wired panel program. This permits the storage of coordinate information at pre-selected intervals during profiling or during contouring in any desired sequence on tape such as *x*, *y*, *z*, *x*, *y*, *z*, etc., or *y*, *x*, *z*; *x*, *z*; etc. The latter sequence is particularly convenient in the profiling mode along lines where $y = constant$. By interrogating *y* only once for each profile and by subsequently recording the *x*, *z*-values for each point, less information is required for storage and the possible profiling speed of the Stereomat may be increased, although this may be impractical as far as the accuracy of image correlation is concerned. A panel with number controls permits pertinent numerical data to be entered manually. This is best done in a specified format so that subsequent digital processing of this information may be possible.

ABSTRACT: *Automatic digital data recording in the B-8 Stereomat in conjunc tion with the Autotrol digitizer and Kennedy tape recorder is described. A program for computing slopes and slope statistics from these data and the resultant output of computer generated slope maps, altitude maps and slope statistics is also discussed with particular emphasis on the possible application of this program to Lunar Orbiter data reduction.*

through the on-line printer of the computer. The form of the output may be in drop lines or in specific symbols for particular elevation zones.

The digitized output has the further advantage that new forms of output on the basis of digitally computed information may be produced at will, such as a slope map.

The following describes an example of such a use of the Stereomat B8. A program for use on the UNIVAC 1108 general purpose computer was developed for producing slope and altitude maps and for reducing statistical slope information from Lunar Orbiter photographs. In designing this computer program it was not intended to develop the direct automation capabilities of the Stereomat further; it originated from the point of view of the user of a production instrument.

The Autotrol Digitizer with Kennedy Tape Unit

The digitizing equipment provides the possibility to digitize *x*, *y*, and *z*-coordinates of successive points representing the floating mark position of the Stereomat. This information is constantly fed into three buffers from where it may be interrogated and placed

The digitizing equipment is capable of recording at constant *x*-intervals varying from 0.1 mm. to 2.2 mm. in steps of 0.1 mm. The Stereomat is designed for constant profile stepping increments in the *y*-direction from 0.5 mm. These *x* and *y*-limits can be interchanged if profiling is carried out in the *y* direction. Orthoprinting is most conveniently done at a 2-mm. interval, and at such an interval the digitizing can proceed simultaneously with orthophoto production.

The stereomat digitizer output consists of a standard IBM binary coded decimal tape with a density of 556 bits per inch.

The Basic Computer Program

BCD/OCTAL CONVERSION

For use in the UNIVAC 1108 computer the binary coded decimal information is converted into octal form which is addressable by the computer. This is done by a special systems subroutine.

AFFINITY CORRECTION

The non-conformity of satellite photography makes it necessary to compensate for differences in principle distance between camera and the Stereomat. For practically parallel exposure directions, as this is the case for Lunar Orbiter photography an affinity correction for the z scale of the digitized stereomodel may be used for high resolution orbiter photography to stay within the principal distance range of the Stereomat B-8. Sometimes Lunar Orbiter moderate resolution photographs require offset to increase the base length for accommodating the Stereomodel in the Wild B-8 plotter; this also requires an affinity correction.

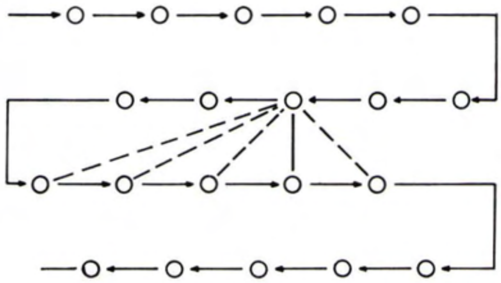

FIG. 3. Calculation of closest digitized point on neighbouring profile for a profile midpoint.

PROFILE OUTPUT

As each profile is being read from tape into core an option is provided to output elevation profiles in graphical form in the 4020 data plotter of the UNIVAC 1108 (Figure 2). After all profiles have been read into core processing starts. In this way the program capability essentially becomes a function of computer memory. The present UNIVAC 1108 program provides the possibility to store 100 profiles of 130 digitized points each which combined with the program occupies a 48,000 word computer core memory. It permits a neat stereomodel to be digitized at 2 mm. intervals. The 130 point limitation per profile has been chosen since the on-line printer of a standard computer has usually a limitation of 131 characters per line, and one character usually represents information about a specific point. The storage of all information in core has been selected on account of the possibility arbitrarily to mirror-reverse or to print a chart in an up-side down manner.

If this possibility does not need to be provided, it is sufficient to operate on three profiles at one time and to store only this information in core. This makes the program practically independent of computer memory. The number of points per profile is only limited by the character per line output capability of the data plotter or the printer. Even this is not a serious limitation, as the information may be printed out in sequential parts which may later on be combined.

ALTITUDE CHART

The elevation may be corrected at this point for model deformation. For Lunar Orbiter data processing a special subroutine has been developed for eliminating the distortions framelet by framelet, which will be discussed later. So that the digitized points with their corresponding elevations may be displayed in their proper geometrical relationship, calculation of the closest digitized point on the following profile is made for the midpoint of a particular profile (Figure 3).

This permits the calculation of a left or right shift for the corresponding characters of the next line for the on-line printer, and therefore the digitized area may be selected with irregular boundaries not perpendicular to the profiling direction. Display on a data plotter could directly make use of the recorded point coordinates.

Because the profiling direction changes by

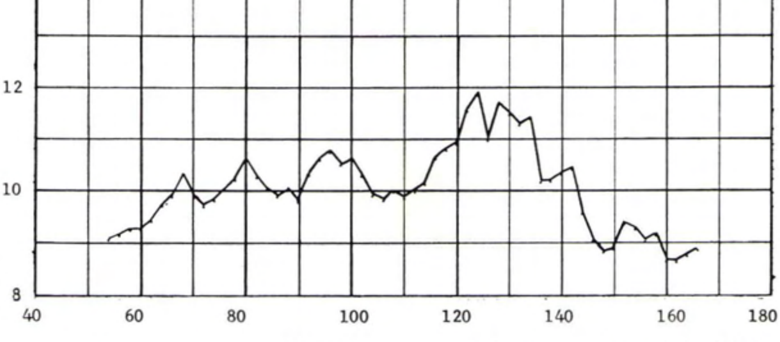

FIG. 2. Graphical Stereomat profile output on the 4020 Data Plotter of the UNIVAC 1108 Electronic Computer.

ALTITUDE CHART

0	LESS THAN	6.988UNITS		
1	FROM	6,988UNITS	TO	8,116UNITS
2	FROM	8.116UNITS	TO	9,244UNITS
3	FROM	9.244UNITS	TO	10,372UNITS
4	FROM	10,372UNITS	TO	11,500UNITS
5	FROM	11.500UNITS	TO	12,628UNITS
6	FROM	12.628UNITS	TO	13,756UNITS
7	FROM	13.756UNITS	TO	14,884UNITS
8	FROM	14.884UNITS	TO	16,012UNITS
9	FROM	16.012UNITS	TO	17,140UNITS

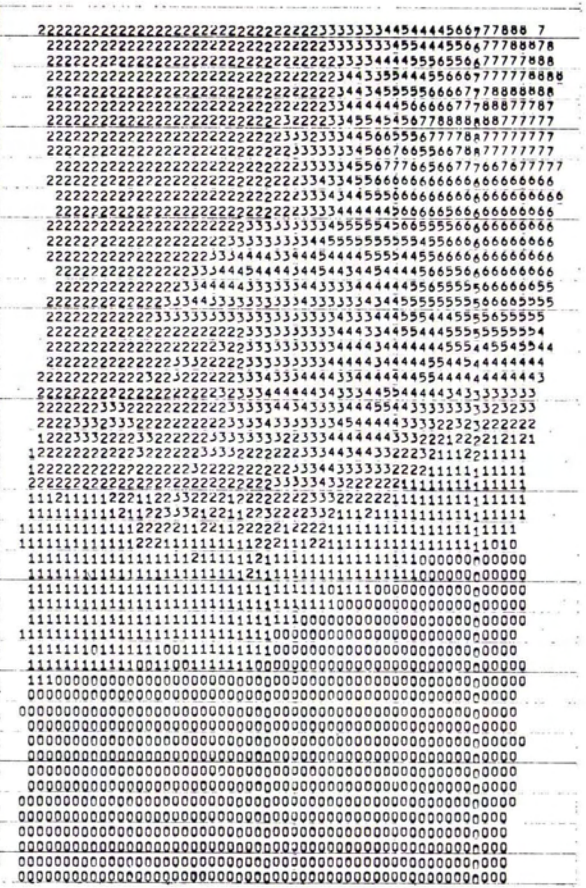

FIG. 4. Altitude chart of digitized area.

180° for alternate profiles, every alternate profile has to be inverted for a printing sequence from left to right. For this it is neccessary to determine the direction of the first profile.

Figure 4 shows an example of an altitude chart for the area depicted in the orthophoto of Figure 5. The altitude chart output on the line printer can take a variety of forms. The output shown in Figure 4 is obtained by computationally forming a maximum and a minimum elevation for the digitized area, by dividing all elevations into 10 cateogries which are displayed by characters from 0 to 9. A legend printed alongside the chart shows the computed limits for each category. This output form is most useful if no knowledge of the elevation distribution of the area exists. In a rerun of the problem in the computer, specific levels may be selected optionally by input. In the present program 20 such levels are provided for, and any numerical character may be selected from any elevation level. For example, if the contour interval is 20 mm. a symbol of 0 may be chosen for a zone from 800 to 820, a 2 from 820 to 840, etc. On the other hand a contrasty sequence which will make the levels stand out better on the map may be preferable, such as 7, 8, 7, 8, etc. There is even the possibility of printing separate charts with particular levels and symbols only. These may later be copied on

FIG. 5. Orthophoto of digitized area.

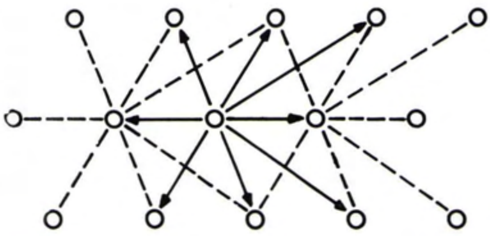

FIG. 6. Slope calculation to adjacent points.

transparencies and used for overlays or for preparation of multicolor off-set masters.

In its simple output form, as shown in Figure 4, the various levels of the altitude chart can easily be separated and enhanced by drawing colored pencil lines between levels. The on-line printer output has the limitation of half a character width for geometrical representation of points on neighbouring profiles. This is not serious for many practical applications. No such limitation exists if the output is made on a data plotter attached to the computer off-line.

SLOPE STATISTICS

For the determination of potential landing sites on the moon's surface the knowledge of slope characteristics of various lunar areas is of prime importance.

The digitized Stereomat records readily enable the calculation of slope information.

For a particular digitized point, slopes are calculated to eight adjacent points; to two points on the same profile, three points on the previous, and three points on the subsequent profile as shown in Figure 6. This calculation is performed for all digitized points with the exception of those on the first and last profiles, as well as the first and last points on each profile. If some of the profile points do not have adjacent points on neighbouring profiles, because the profiles either vary in length or are offset in the x-direction, calculation of slopes is interrupted for the particular point and a special symbol is reserved for the point output with the meaning that all 8 slopes cannot be calculated. For every point the maximum slope of the 8 calculated ones is also stored. Except for the rays to border points of the digitized area every possible absolute slope will be calculated twice.

As the calculation proceeds it becomes possible to test every calculated absolute slope to determine whether it falls into a particular category of magnitude such as between 0° and 2°, 2° and 4°, 4° and 6°, etc. This can also be done for the maximal slopes.

SLOPE CHART

0	FROM	0,DEG	TO	2,DEG
2	FROM	2,DEG	TO	4,DEG
4	FROM	4,DEG	TO	6,DEG
6	FROM	6,DEG	TO	8,DEG
8	FROM	8,DEG	TO	10,DEG
A	FROM	10,DEG	TO	12,DEG
B	FROM	12,DEG	TO	15,DEG
C	FROM	15,DEG	TO	***DEG
X	ALL 8 SLOPES CANNOT BE CALCULATED			

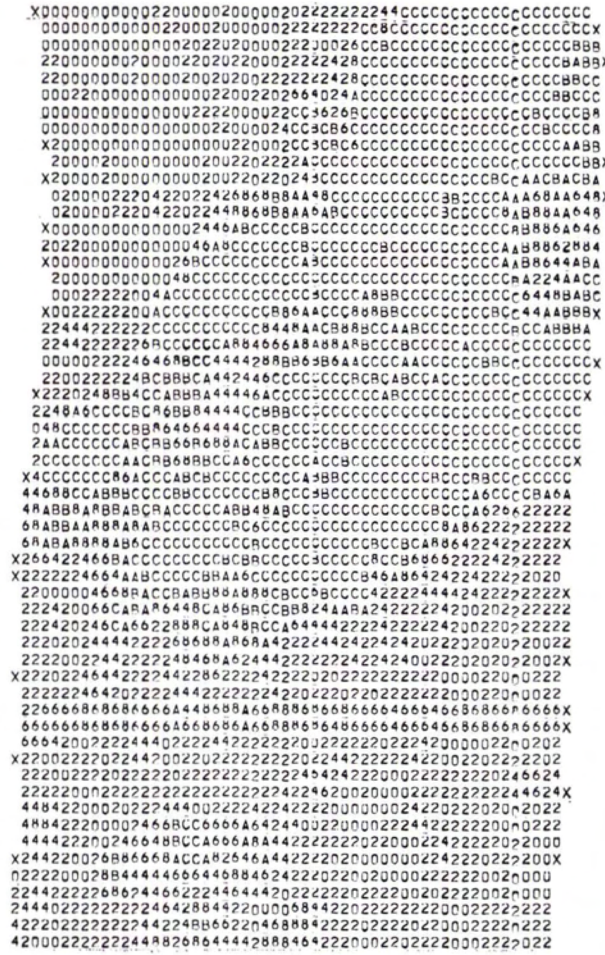

FIG. 7. Slope map of digitized area.

The number of slopes falling into a specific category can be counted up and histograms for slopes and maximum slopes showing the statistical distribution of their magnitudes may be prepared for each area profiled with the Stereomat. Such data may serve as indicators for surface roughness of selected areas.

Slope Maps

It may also be useful to display the maximum slope information in a form similar to that described for the altitude charts. Figure 7 shows an example of such a slope map in which alphanumeric characters have been chosen to represent certain slope categories. The remarks made with respect to output media, output limitations and output forms of the altitude charts likewise apply to slope maps.

Subroutine for Adjustment of Model Deformations

The particular usefulness of digitized model data is the possibility to correct for model deformations. In evaluating transmitted Lunar Orbiter photography the segmentation of each moderate resolution photographic frame into 26 framelets each of which contains its own unique pattern of distortion, necessitates the elimination of model deformation for every framelet combination of the two-frame stereo-model. Analytical aerial triangulation of all frames overlapping by 87 percent permits the determination of a considerable number of control points for each of the framelet combinations. The redundacy of analytical aerial triangulation with 87 percent overlapping photographs promises to eliminate a significant part of the systematic deformation present. In this way each Stereomat model may be adjusted framelet by framelet for the model deformations characterized by discrepancies between stereomat heights and heights resulting from the analytical aerial triangulation.

For this purpose a series of control configurations is measured in the Stereomat right after or before digitizing the model in profiling mode. The coordinates, identification numbers and the triangulation heights can be entered sequentially on tape.

Figure 8 illustrates the manner in which the information is treated in the computer. The control consists of two linear sequences of control points *P(1,1)* to *P(1,m)* to *P(2,1)* to *P(2,n)*, etc., for each framelet (1–2, 3–4, etc.). The two sequences for each framelet

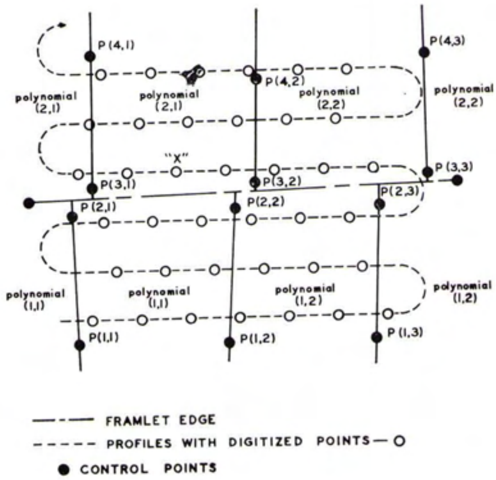

Fig. 8. Control configurations for eliminating model deformations.

must have the same number of control points. Then it becomes possible to calculate adjustment polynomials of the form:

$$\Delta Z = a_0 + a_1 x + a_2 y + a_3 xy$$

for each control configuration such as that formed by points *P(1,1)*, *P(1,2)*, *P(2,1)*, *P(2,2)* or by points *P(1,2)*, *P(1,3)*, *P(2,2)*, *P(2,3)*, etc.

Although x and y represent model coordinates, and Z the difference in triangulation and Stereomat model heights, a_0 to a_3 are the polynomial coefficients to be stored for later use.

When a point is processed in the main program for representation in profiles, altitude or slope maps, tests are made as to which of the control polynomials the point belongs. Point x in Figure 8 would for example fall into the area represented by polynomial *(2,1)*. The tests use simple analytical line geometry. The present program has provision for a sequence of 30×15 polynomials in the y and x-directions. Such limitations are merely a function of convenience with respect to the type of computer storage used. Obviously the use of such adjustment polynomials is not restricted to Lunar Orbiter photography but can be applied to any situation where four or more control points are available.

It may be undesirable to include points close to the framelet edges into the calculations because Stereomat elevations close to a framelet edge may contain errors due to the influence of the adjacent framelet pair. For this purpose a tolerance may be used. If the point lies closer to the framelet edge than the introduced tolerance value, calculation of slopes will not be made for the point; a special symbol will be used in both slope and altitude chart outputs (x on slope maps and *blank* on altitude charts).

Contour Maps

The 4020 Plotter of the UNIVAC 1108 also permits the production of contoured maps from digital information by use of a special contouring subroutine. This subroutine may be applied to digitized stored z data for x, y-coordinates; in this way one may prepare computer generated contour maps which show numbered contours at specified intervals. Similarly, slope maps with contours of equal slope could be prepared. At present these options have not been incorporated into the program; the numerical representation is considered equally effective for present use.

Conclusion

It would go beyond the scope of this paper to discuss the ideal spacing, the ideal speed, and the accuracy limitations of digitizing lunar and other Stereomat models. Likewise only preliminary estimates for the derivation of slope maps from digitized data are possible for certain spacings. For a 2-mm. spacing, the slopes can be expected to be certain to a standard deviation of $\pm 1.5°$ if we disregard control point errors. Experimentation with the programs as to best spacing, Stereomat speed, the distribution and density of control and the best suitable form of output is necessary.

At this stage it is quite clear, however, that digitized Stereomat data offer a wide variety of further processing possibilities, as far as information content and output means are concerned. Depending on the extent of the adjustment, the present program can process a stereo-model with all described options in two to five minutes on the UNIVAC 1108.

Articles for Next Month

A. Arena and *M. Umlas*, A new panoramic camera development.
Peter C. Badgley, *Alden P. Colvocoresses*, and *Charles D. Centers*, NASA earth-sensing space experiments.
William R. Hemphill and *Walter Danilchik*, Geology from a Gemini V photo.
Jacob Klaver, Kern plotter improvements.
Ray Lafferty, Jr., Circular flight paths using DME.
Prof. Francis H. Moffitt, Wave surface configuration.
Geraldine M. Wuollet and *Herbert E. Skibitzke*, Plotting DME arcs for aerial photography.