J. V. SHARP*
R. L. CHRISTENSEN
W. L. GILMAN
F. D. SCHULMAN
*Data Systems Division*
*International Business Machines Corp.*
*Kingston, New York*

# Automatic Map Compilation Using Digital Techniques

**Technical feasibility of the digital technique has been demonstrated by producing contour maps having a C-factor greater than 250 in less than an hour per model.**

(*Abstract is on page 226*)

## INTRODUCTION

DURING the period of this Digital Automatic Map Compilation (DAMC) development, several stereo aerial models from test areas were successfully compiled into contour maps and orthophotos. These were prepared with a digital map compilation system consisting of an IBM 7094 computer (Figure 3) and an experimental digital diapositive scanner-printer, combined with a WILD STK-1 stereocomparator (Figure 1). Technical feasibility of the digital compilation process was established by the successful production of contour manuscripts and orthophotos, which was the objective of this experimental effort. The digital map compilation process was tested with several sets of stereo aerial photographs representing various types of terrain and camera orientation.

Present digital compilation methods provide substantial improvement in the rate of handling large quantities of photo data in a stereo pair, with a resultant map compilation time on the order of tens of minutes, depending on the programming system used. Two major programming systems were developed: the sequential system, which is accurate and fast, and the predictive system, which is presently faster but less accurate in map compilation.

The sequential programming system is an in-line operational approach which divides the map compilation process into five phases:

1. Resection-orientation.
2. Rectification.
3. Digital image correlation and parallax calculation.
4. Contouring and orthophoto correction.
5. Tic mark insertion.

A block diagram of the DAMC sequential system is shown in Figure 9. The resection-orientation program determines the camera orientation and is based upon the Church resection method. The tilt, swing, azimuth, and nadir location are computed for each photograph of the stereo pair. The output of this program is used to align the stereo-diapositives properly on the WILD STK-1 stereocomparator for scanning parallel to the flight line and to provide certain parameters which are required for rectification.

The rectification program repositions the digitized photographic data to compensate for displacement caused by tilt and scale.

* Presented at the Tenth Congress of the International Society of Photogrammetry at Lisbon, Portugal, Sept. 7, 1964. The material in this paper has been cleared for open publication by the Department of Defense. Review of this material does not imply Department of Defense endorsement of factual accuracy or opinion.

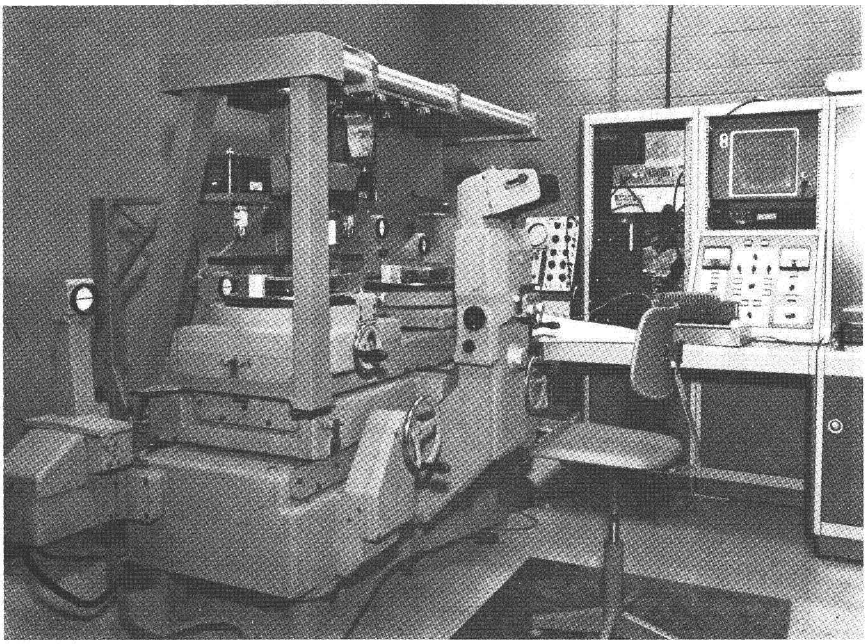


FIG. 1. IBM photo-digitizing stereocomparator.

The "successive parallax approximation" is a method of pattern matching to determine conjugate imagery which combines a statistical correlation formula with several ways of processing the photo data thereby reducing computer processing time to an acceptable level. After considerable evaluation and testing with simulated photographs and actual stereo photographs, this correlation technique was integrated in the DAMC sequential system.

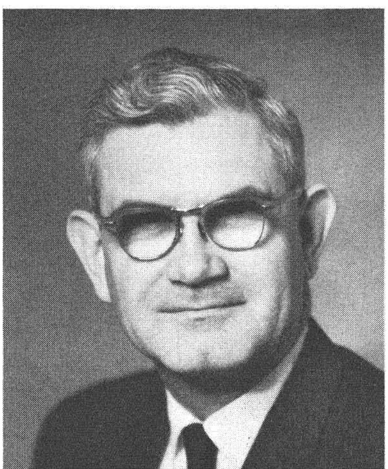
The contouring and orthophoto programs produce the digital data required to print the final orthophoto and a contour map. Corrections are made for the displacement of images due to relief, and the photograph is appropriately scaled so that the resulting orthophoto is a true map with a uniform scale.

The tic mark placement routine superimposes a grid over the photographic data in the orthophoto map; this placement is equivalent to 1000-meter intervals on the ground relative to a known geodetic origin. Similar tic mark symbols can be inserted on the contour manuscript. These combined programs result in the complete sequential programming system.

The predictive programming system is an alternate technique which consolidates control, contouring, and ortho-correction of the digitized photographic data. This system (Figure 10) has three main programs to process the digital data:

1. System control program
2. Direct contour program
3. Direct orthophoto program

The system control program is currently operational and is now operating with rectified photo data from various models. Its ability to use unrectified data is planned for



JOHN V. SHARP

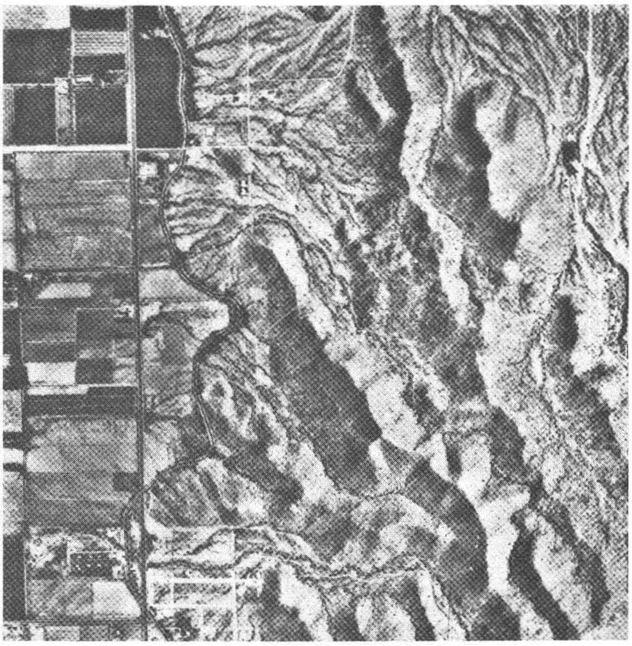


FIG. 2. Aerial diapositive (one of a stereo pair).

the future. The program is sufficiently complete to demonstrate digital mapping feasibility by producing orthophotos and contour overlays on these models.

This system control program, when using unrectified data, will convert ground and interior orientation measurements (using resection and orientation parameters) to a set of tables for controlling the direct contour program. These tables, which can be subsequently expanded for optional use in the direct orthophoto program, will contain rectification shift data for all distortions, control points, tic markpoint locations, and symbols. The tables will also include secondary control points which define non-correlatable areas by the perimeters, such as built-up areas, lakes, bay surfaces, etc. Shift of data for final map projection will also be part of the program.

In the direct contouring program, the digitized photo pair data are processed to reduce the storage of photo data to a minimum time and amount. The photo pair is processed with rectification shift data, using point correlation among a set of predicted conjugate image points. A set of ortho-corrected parallaxes and elevations is produced first; then the contouring routine completes the program.

In the direct orthophoto program, a set of rectification and relief displacements is first

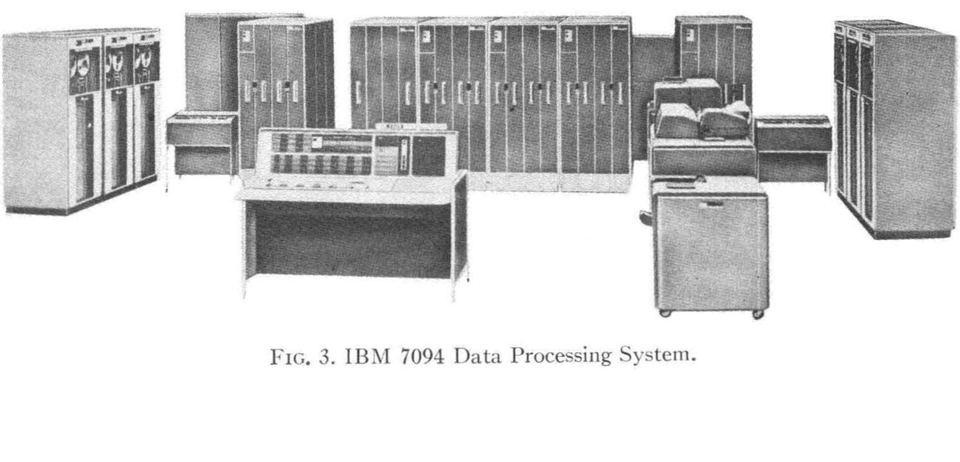


FIG. 3. IBM 7094 Data Processing System.

processed and stored for use in direct conversion of a digital photo to an orthophoto. The contour tape with rectification and relief displacement data is converted to digitized orthophoto data. This data is moved once directly to its ortho-corrected position with a minimum number of data shifts. The output tape produced then contains the digitized orthophoto data ready for printout on film or diapositive, using the digital printing system. This program is complete and will work with rectified or (when available) with unrectified photos, using tabulated shift data.

## System Configuration

### Equipment

The Digital Automatic Map Compilation (DAMC) system is built around an IBM 7094 (Figure 3) Data Processing Unit (other processors of comparable power could be used) and the experimental DAMC photo-digitizer (Figure 1). The photo-digitizer consists of two major sections:

1. The Magnetic Tape Units and Magnetic Tape Adapter Unit (TAU).
2. DAMC scanner-printer combined with a WILD STK-1 stereocomparator.

Abstract: *Automatic map compilation using digital techniques is progressing at IBM in Kingston, N. Y. These advances represent over four years of research and development, supported primarily by the United States Army, GIMRADA, Ft. Belvoir, Va., and IBM. Other agencies have supplemented this effort in collateral application areas.*

*Experimental systems have been developed that are capable of digitizing and processing photographic data of various quality levels, ranging from TV-satellite, X-ray, and radar-camera quality to that obtained with aerial-reconnaissance and precision-mapping cameras. Up to one hundred million bits of digitizable data are scanned from a stereo photo and recorded on magnetic tapes for data processing purposes.*

*In the digital map compilation system, data associated with a pair of aerial photographs are simultaneously digitized. The most important data of this type are those concerned with control, obtained from ground-control surveys, and related measurements made on an experimental photo-digitizing stereocomparator; and other digitized data required consists of flight data, lens data, and other instrument calibration measurements. This digitized photo and control measurement data are recorded on tape for processing with a computer.*

*Although these operations are basically automated, human skill is required for the stereoscopic identification and precise measurement of diapositive control points. In addition, the final editing of maps to conform to topographic practice requires the skill of expert cartographers.*

A series of systems test procedures was generated to perform an evaluation of both the DAMC sequential and predictive systems. The procedures, either in the form of a measurement or a computer program, measured the effects of each process of the compilation system and the total system capability of producing contour manuscripts. Test procedures were developed to:

- Compute the *C*-factor (vertical accuracy).
- Compute horizontal accuracies.
- Measure residual *y*-parallax in rectified photographs.
- Compute the spot placement error in the scanner with computer-generated grids.
- Verify the rectification process with digital checks.
- Measure operating time.

The tape units serve as storage media for computer input and output data. The TAU, in addition to serving as an interface, provides timing pulses and synchronization logic for the entire system. The scanner-printer unit has two functions:

1. To convert photographic image information to digital information in standard IBM tape format (accomplished in the Scan Mode).
2. To convert digital data stored on magnetic tape to photographic image information (accomplished in the Record, i.e., Print Mode).

Since the quality of maps compiled by the

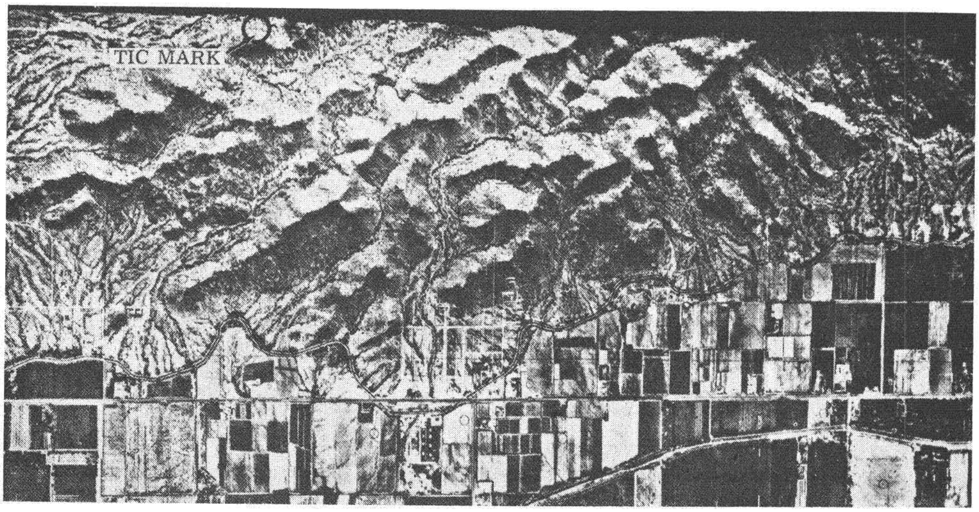



FIG. 4A. Ortho-corrected photograph.

digital process is ultimately limited by the quality of the input data, the scanner is a critical unit in the system. Hence, the image-to-digital conversion process is extremely important.

The scanner was designed and built with the following capabilities:

1. The system provides a means of precisely orienting stereo diapositives in the stereocomparator to permit accurate measuring and recording of fiducial marks, principal points, control, and pass-points in the two photographs. The conjugate measurements are recorded in terms of a photo-coordinate system and are entered as input digital data to the aerotriangulation program (resection and orientation).

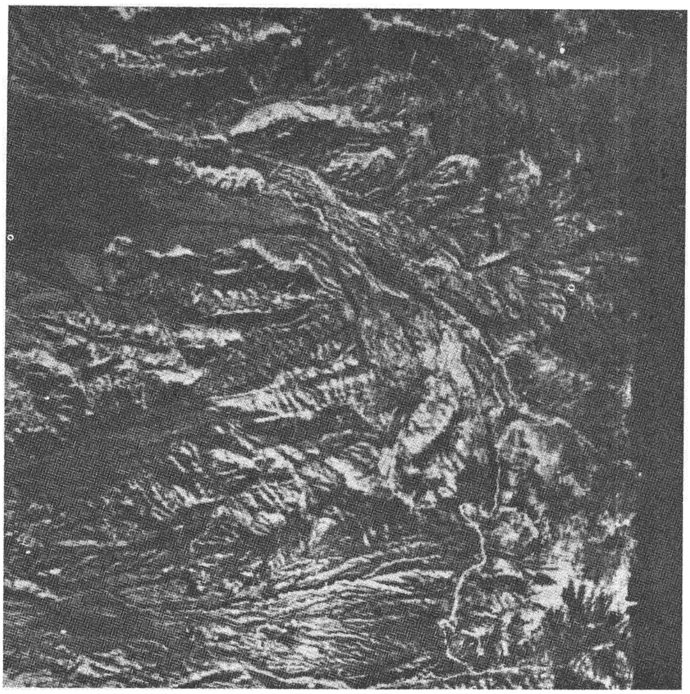


FIG 4B. Ortho-corrected photograph.

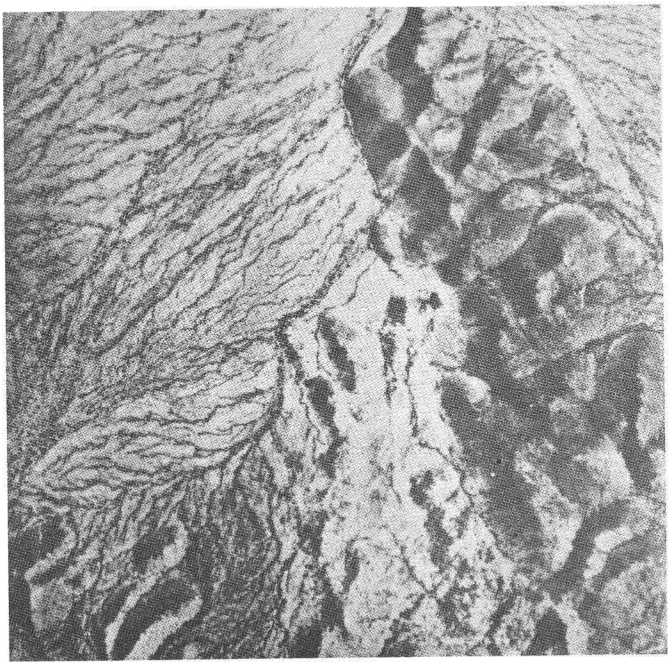


Fig. 4C. Ortho-corrected photograph.

2. In the Scan Mode, the system simultaneously scans and digitizes the overlap areas of a stereo pair (approximately 4.5″×9″). The scanner is capable of scanning at resolutions of 16 or 32 spots per millimeter in $x$ and $y$ directions and is also capable of image-to-digital conversion at levels of 8, 16, or 32 gray

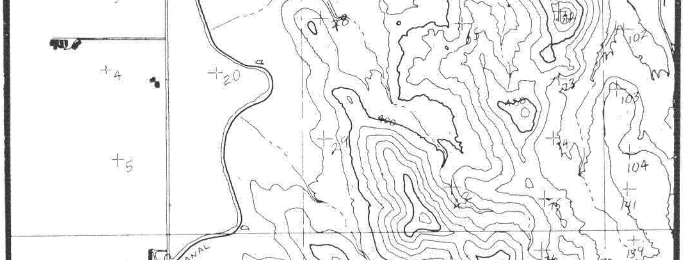



Fig. 5. Manually drafted contour map manuscript.

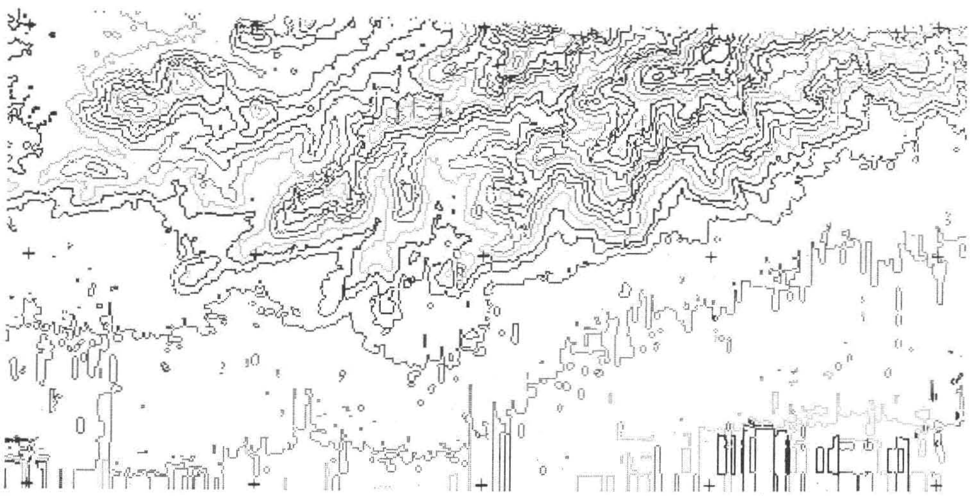


FIG. 6A. Contour map produced by the sequential system.

shades (although the signal-to-noise ratio with present light intensity is sufficient for useful operation only in 8 levels).

3. In the Record Mode, the system converts digital information to modulate a light beam to expose a photographic film. The same resolution and gray-shade range described above are available in the Record Mode.

The DAMC Scanner-Printer is an electro-optic-mechanical device, consisting of the following major elements:

1. WILD STK-1 stereocomparator—This unit functions as both a measuring machine and a scanning bed. The stereo

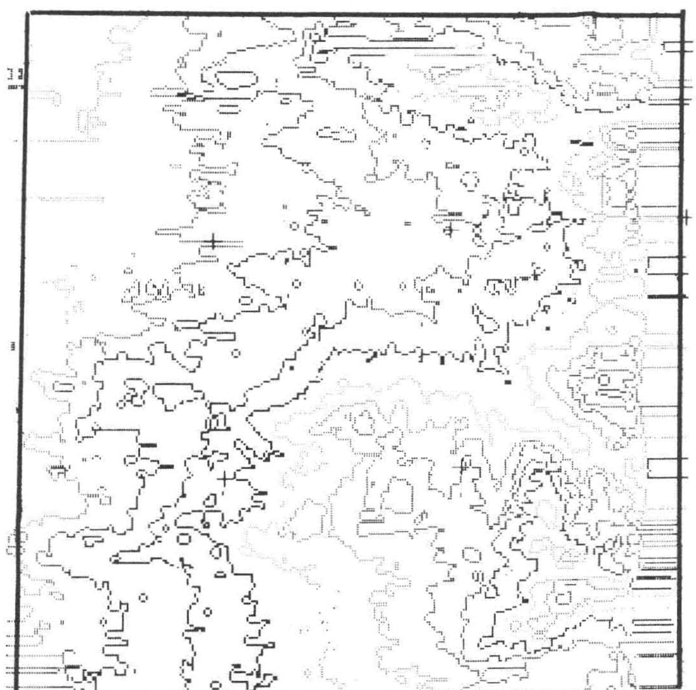


FIG. 6B. Contour map produced by the Sequential System I.

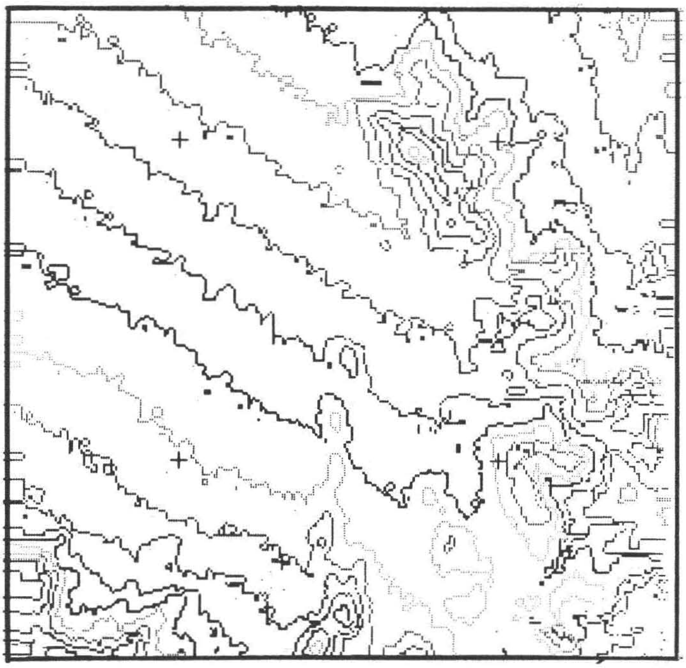


FIG. 6C. Contour map produced by the Sequential System I.

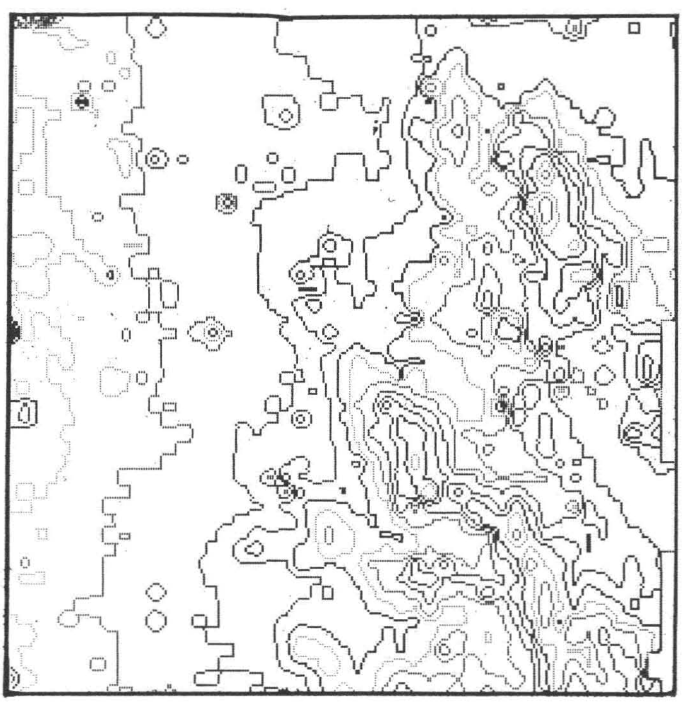


FIG. 7A. Contour map produced by the Predictive System II.

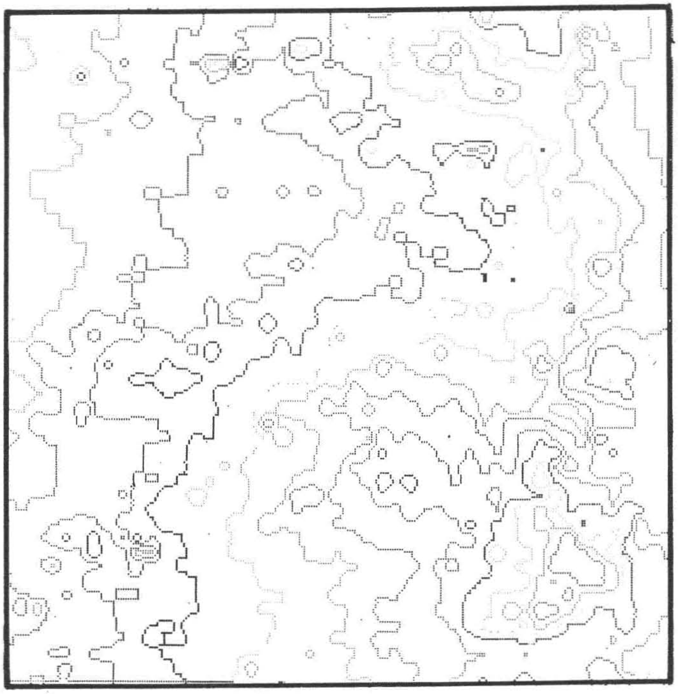


FIG. 7B. Contour map produced by the predictive system.

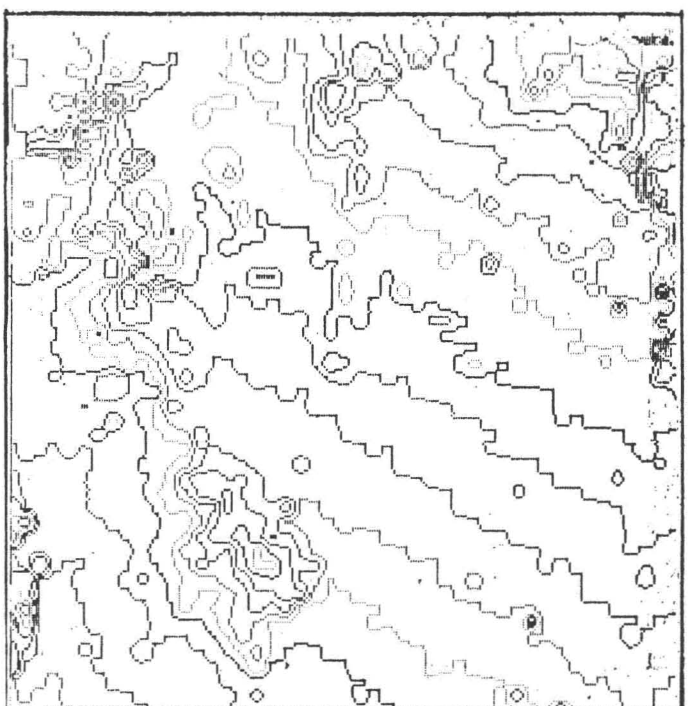


FIG. 7C. Contour map produced by the predictive system.

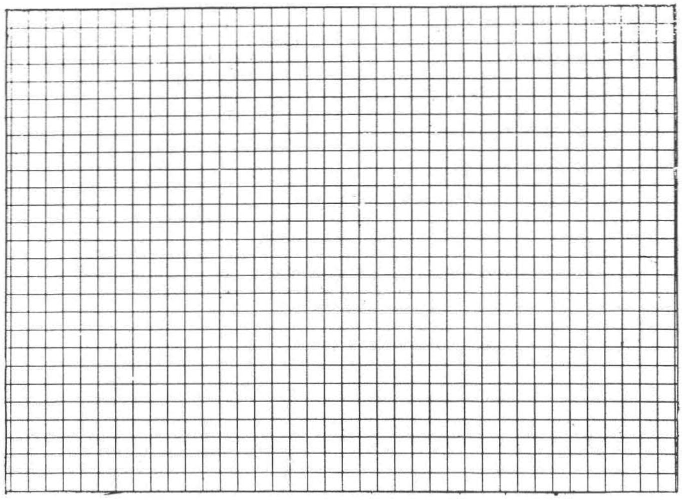


FIG. 8. A Grid.

plates are mechanically transported in the $Y$ direction during the scan operation at a constant rate of approximately 7 mm per second.

2. A line-scan cathode ray tube is the light source for scanning and recording. The light-producing electron beam is incrementally deflected in the $x$-direction by digital and analog electronic circuitry at a 15-kc rate.

3. Optical elements (lens, mirrors, beam splitters)—The light beam emanating from the phosphor surface of the CRT is split, focused, and directed to identical photo-coordinate positions by a lens system. The light passing through the diapositives is directed by an optical collector to the sensing photomultiplier tubes.

4. Photomultipliers—which produce a voltage output proportional to the impinging light and, hence, to the transmissivity of the area of the diapositive being scanned.

5. Linear amplifiers, with adjustable gain, which match the photomultiplier outputs to the A/D converter inputs.

6. A/D converters—A voltage level of 0 v to 5 v is provided at the A/D converter input. The exact voltage level is proportional to the "gray shade" of the incremented area being scanned. The voltage signal is quantized by the converter in 8 (or 16 or 32) equal increments, and the appropriate number of bits is assigned, based on the quantization level.

7. Control logic—which allows the scanner to be operated in a continuous sequential mode and is also used to initiate and halt operations. Figure 11 shows a schematic of the Scanner System.

OPERATION

Since digital computers operate only with discrete data, the conversion of the pictorial content to digital data is a prerequisite for this form of photographic data processing. The Scan Mode of the modified WILD STK-1 is used to sample the approximate transmissivity ($T$) of definite areas on the photograph and convert them to an 8-gray-shade (or "density" level) code. Each gray-shade value is coded into a binary number and combined with an error-check code before being transferred to magnetic tape.

Because of the line-scan tube characteristics and the limited size of internal memory, the data on tape is grouped in convenient-size blocks, called a scan record. This record consists of the 1728 gray-shade values of a 4.32-inch scan (linear density of 16/mm). Since the scanner digitizes two photographs simultaneously, two gray values are packed into a single character. The three low-order binary bits carry the right photo gray codes; the three high-order bits carry the left photo gray codes. The IBM 7094 takes its input from a 7-track binary tape; six tracks contain a pair of gray values and the seventh contains an error-check digit. Each 7-bit code forms a character, and 200 characters are stored on 1 inch of tape. A $\frac{3}{4}$-inch gap is placed between two records. These data are then an input to either DAMC programming system.

## System Programs

### SEQUENTIAL PROGRAMMING SYSTEM

One experimental program system consists of five programs in the following sequence:

1. Resection-orientation
2. Rectification
3. Successive parallax correlation
4. Ortho-correction and contouring
5. Tic mark placement.

Figure 9 shows the information flow through the sequential programming system.

### *Resection-Orientation Program*

The Resection-Orientation program requires that every pair of stereo diapositives be accompanied by a set of selected points whose images on the photograph can be positively identified with their corresponding objects on the ground. These control points to enable orienting the photographs with respect to a ground survey. The relationship of stereo map photographs to geodetic coordinates can be determined by their ground-control information, focal-length, and camera flying-height. A WILD STK-1 stereocomparator is used to measure coordinates of the ground-images as well as the fiducials of the photographic diapositives.

The ground control data and diapositive measurements are converted to a punched card format, which is used as the input to the Resection-Orientation program. This program computes the tilt, swing, azimuth, and nadir and related matrix of each photograph. The coordinates of both the nadir and conjugate nadir of each photograph are provided as input to the scan process, in which both photographs are scanned parallel to the flight line. The program also puts out additional data required as an input to the rectification program.

### *Rectification Program*

The input to the rectification program consists of information supplied by the Resection-Orientation program, measurements from the stereocomparator, and photo data on two

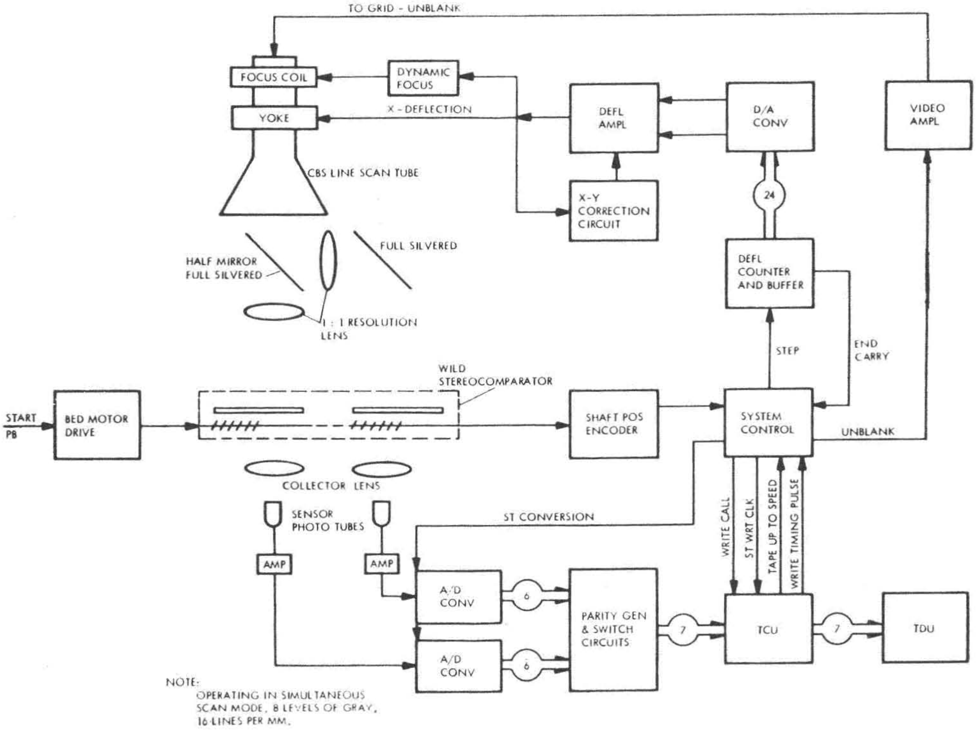



FIG. 9. Simplified scan operation logic.

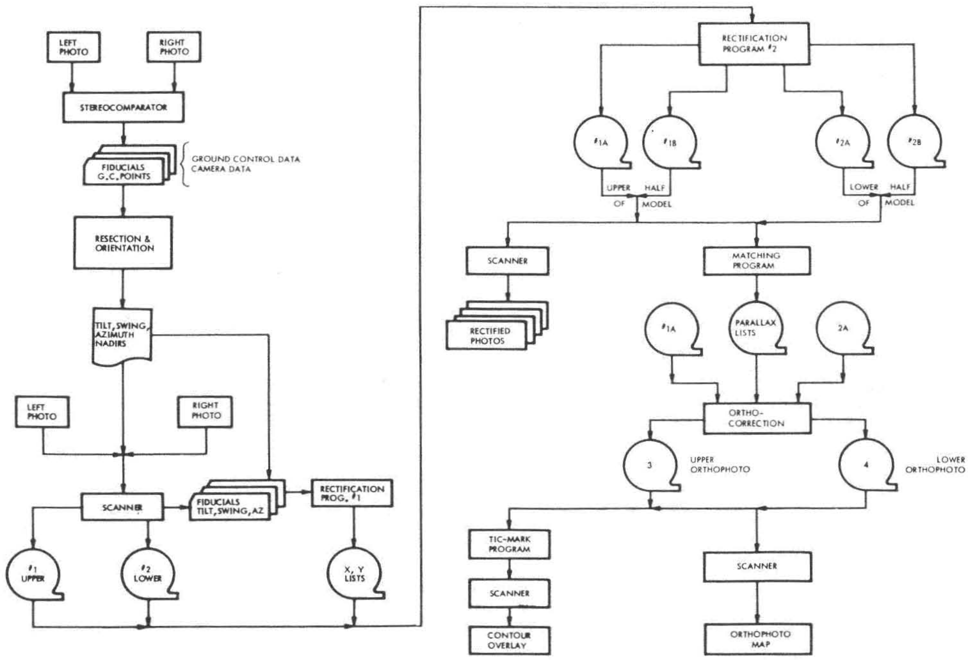



FIG. 10. DAMC Sequential Program System flow chart.

magnetic tapes. One tape contains the packed binary-gray shades from the two upper quadrants of the stereo pair, and the other, those from the lower half model. The first phase of the rectification program computes the $x$ and $y$ data shift lists required to carry out rectification and scaling. It also accepts data on the stereo images of the left and right nadir-points and produces information needed for the ortho-correction program.

The scanned data and rectification lists are used to modify the scanned data in both the $x$ and $y$ directions. An output area is reserved in core memory to store a maximum of 100 scans. Once this area filled with rectified data, the maximum number of full scans are written on an output tape. The incomplete section is moved down to become the start of the next rectified block. This process continues until the entire input data tape is exhausted and the program is complete and ready for a correlation program to measure $x$-parallax differences.

*Successive Parallax Correlation Program*

The correlation method of successive parallax approximations is based on two fundamental ideas: convergence to a solution by stages of increasingly accurate parallax measurements, and use of statistical correlation of image data to find matching areas. The idea of convergence is implemented by using digital images of reduced resolution. The reduced images can be computed quickly. A single area of one image is matched by computing correlation coefficients for several overlapping areas of the other photo. The greatest correlation coefficient is the criterion of best match. A correlation coefficient between $x$ and $y$ is conventionally represented by the letter "$r$" as defined by

$$r = \frac{\text{co-variance }(x, y)}{S_x \cdot S_y}$$

$$x = D(\text{density level of left photo point})$$

$$y = D'(\text{density level of right photo})$$

The denominator of the formula is the product of the sample deviations for $x$ and $y$, the density levels in the sample areas of left and right photos, respectively. The formula used for the sample deviation is:

$$S_x = \sqrt{\overline{x^2} - \bar{x}^2}, \qquad S_y = \sqrt{\overline{y^2} - \bar{y}^2}$$

where

$$\bar{x} = \frac{1}{n}\sum_1^n x_{1i} \quad \text{and} \quad \overline{x^2} = \frac{1}{n}\sum_1^n x_i^2$$

(similarly, $\bar{y}$ and $\overline{y^2}$)
The formula for co-variance is:

$$\text{cov}\,(x, y) = \overline{x \cdot y} - \bar{x} \cdot \bar{y}$$

where

$$\overline{x \cdot y} = \frac{1}{n} \sum_{1}^{n} x_i y_i$$

The method of successive parallax approximations can be illustrated by a description of the present program which consists of four parts, designated (*A*), (*B*), (*C*), and (*D*). The first program part (*A*), uses the basic image data with a scan resolution of 16 spots/mm and produces new digital images of lower resolution. The lower resolution permits a given photo area to be represented by far fewer digits. The other three parts of the program perform image matching at three other successively higher levels of resolution, approaching that of the real photo.

The three parts of the program which perform matching are similar in plan. At each level of resolution, the shrinking sample area is used. Three sample sizes are used in part (*B*), a 12×12, a 6×6, and a 3×3 array of spots. Only the two smaller sizes are used in the last two parts of the program, (*C*) and (*D*). All correlation done with images at a single resolution is called a "stage" of correlation or matching. Part (*V*) controls the first stage of matching.

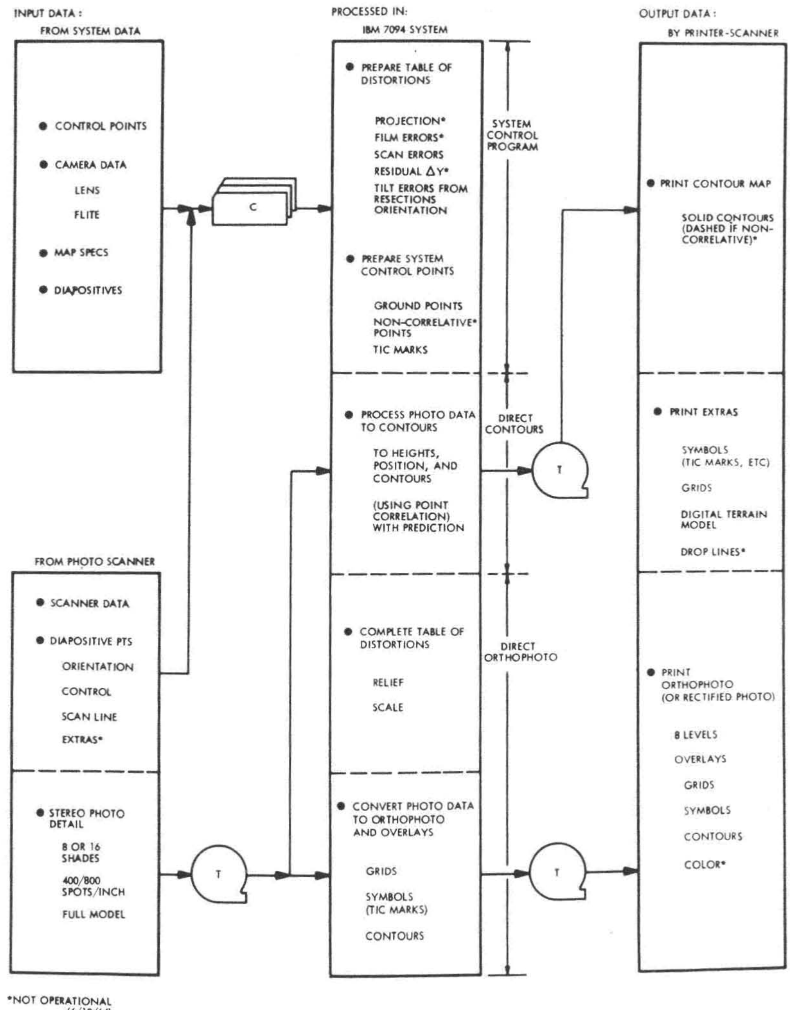



FIG. 11. Predictive programming system diagram.

The general procedure of matching will be described in geometric terms. The left photo is considered to be divided into square areas, and each square, in turn, is considered in an attempt to find a matching area in the right photo. All of the squares forming a horizontal (parallel to $x$-axis) band are considered before considering squares in another band. The second and third stages of matching are similar in operation to the first stage.

There is enough room in the computer memory to store the parallax approximations for parts (*B*) and (*C*). The parallax approximations found by part (*D*), with interpolation where necessary, are written on a tape as each band or strip of the left photo is matched. Each parallax difference on the output tape corresponds to a 6×6 spot area of the full-resolution left photo.

*Ortho-correction and Contour Program*

An orthophoto map with contours is produced after the correlation process. It represents an orthogonal view of the ground in which each object appears as though it is viewed from vertically above. Image displacement caused by relief is one of the more significant errors in a real photograph resulting from the perspective view of camera-lens combination. The orthocorrection program corrects for image displacement resulting from relief and, in conjunction with the WILD reproducer unit, generates an orthophoto map and/or a contour overlay.

The 6×6 photo spot increment (15-mil square) on the left rectified photo tape is moved to its orthographic location on the basis of its elevation relative to the nadir-point. Groups of six scans of rectified data are transferred into an input buffer where the elevation of each 6×6 spot area is computed from its associated parallax, previously derived from the correlation phase and stored on a parallax tape. Each 6×6 spot area is assigned an elevation which, in conjunction with a series of algorithms, places a contour marker in each area whenever the elevation moves to the next higher or lower contour level. The contour placement algorithm verifies that each contour line is continuous and closes upon itself. After a correction factor is applied to the coordinates of each elemental area, the data are shifted from the input buffer to its new or ortho-corrected location until it is written on tape. The format of the output tape contains the ortho-corrected photographic data in the low-order bits of a character, with the contour spot markers appearing in the high-order bit.

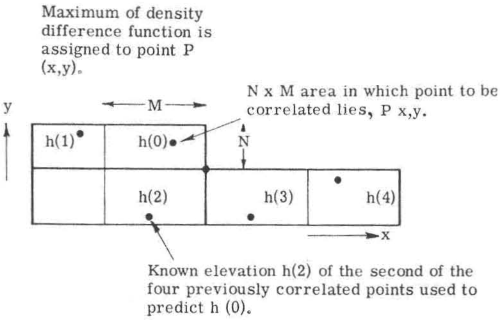



FIG. 12. Predicting parallax of $P(x, y)$.

The present format for recording contour information on an overlay is as follows:

1. Every fifth contour interval receives a darker shade of gray that makes it more discernible than the other contours.
2. Each contour line is represented by a unique symbol to differentiate it from the adjoining contours. Five different symbols are available. A contour line is generated by interconnecting a series of 6×6 spot areas in which the photographic detail has been replaced by an appropriate symbol.

These marks are placed at each point where the parallax difference changes to a new contour interval, producing a contour map in digital form.

*Tic Mark Program*

Planimetric maps usually contain identifying information that shows the position of the photographs relative to some ground coordinate system. The Tic Mark program inserts markers at 1,000-meter latitude and longitude intersections on the orthophoto or contour map. Based upon ground-control information and flight angle, an imaginary grid system is constructed to the scale of the map and oriented in a north-south direction. Those photo locations that coincide with a grid intersection are marked so that they can be identified on the final contour map.

### DAMC PREDICTIVE SYSTEM

The major operational parts of the predictive system are essentially completed (Figure 10). The scope of this effort was to develop and show feasibility for a second experimental programming system, and thereby to increase the system flexibility by providing an optional approach to the speed-accuracy compromise.

In the predictive system, the significant parts of the planned system having major effect on time and accuracy have now been programmed. The description and status of the three program sections of this system follow. The use of unrectified data is planned and partially programmed, but it is not yet operational.

*System Control Program*

The system control section organizes all the forms of input system control data for use in direct contouring and orthophoto program sections. The data are made available in the form of tables and mathematical formulas, depending upon the most efficient manner in which the data can be retrieved with respect to required accuracy, computational speed, and storage requirements.

This program functions as a central control monitor with respect to position or tic mark data and control symbols, resection-orientation parameters, ground survey data, parametric limit tables for use in contouring, output scale of orthophoto, and non-correlatable areas. The tables and formulas enable optimization (speed vs. accuracy) of the predictive system operation when using point (as opposed to "area," as in the sequential system) correlation.

*Direct Contouring Program*

The direct contouring program has two parts: correlation and contouring. The predictive point-correlation program initially examines the digitized left photographic data in an $N\times M$ area and determines the position of a single point within this area as possessing the "best" characteristic. This characteristic is determined by the use of one or more density (digitized transmissivity) difference functions $f(\Delta D)_{xy}$, whose value is "best" in each $N\times M$ area in the left photo, where "best" implies, essentially, maximum change of photo density, i.e. detail.

The function $f(\Delta D)_{xy}$ at the point $x$, $y$ represents a point correlation process, and the concept of a density function is based on the premise that all "$x$" directed changes in density are critical to any correlation process. In general, this function is simply defined as $(f\Delta D)_{xy}$ where

$$f(\Delta D)_{x,y} = \Delta D_{1,2} + \Delta D_{3,4}$$

where

$$\Delta D_{1,2} = D_1 - D_2 \quad \text{and} \quad D_n = \sum_{j=0} \sum_{i=0}^{k} D_{x+i,y+j}$$

with magnitude and sign constraints on $k$, $l$, and $\Delta D$.

A threshold value or cutoff limit is assigned to the density difference function below which all values are rejected. This minimizes the necessity of accepting any system noise from optical, photographic, or electronic sources, within the photographic data.

The subsequent $f(\Delta D)_{x,y}$ to be compared with this initial value is at point $(x+S_{x,y})$ in the $x$-direction and at $(x,\ y+S_y)$, in the $y$-direction where $S_x$ and $S_y$ are shifts in the $x$ and $y$ direction, respectively.

As described above, a value of the selected density difference of any point $x$, $y$ in the photo relative to its neighboring points is developed from the scanned photo data. An optimum (empirically determined) density difference function is then used to examine all density differences and to select that point in $N\times M$ area which possesses the "best" characteristic (i.e., the one that yields the most valid correlations per photo). The sample area $(N\times M)$ is currently $36\times 36$ spots.

Having searched and found a maximum of the appropriate density difference function of one point within the $N\times M$ area, the predicted parallax limits of this point must then be determined in order to locate the conjugate point in the right photograph. This determination is accomplished by first predicting its average elevation (using known distortions where required), and then predicting its minimum and maximum elevation, by using four known elevations which are adjacent to the point in question. Refer to Figure 12.

These four known elevations are previously correlated points. Their spatial positions in the photograph have been determined as shown and lie at various points within the $N\times M$ areas. The "$h(0)$" is located somewhere within the indicated $N\times M$ area, and its elevation and exact position are to be determined by matching rules.

The predicted average elevation is

$$\bar{h}_{x,y} = \frac{1}{n} \sum_{i=1}^{N} h(i). \qquad n = 4 \text{ in Figure 12}$$

The range in predicted elevation (computed to corresponding parallax) is then computed where $h(n)$ has maximum and minimum values and

$h(n)_{max} - h(n)_{min} = r,$ the range.

With rectified data, three $x'$, $y'$ coordinates predict the selected upper limit, lower limit, and the center of the resultant search range ($r$) in the conjugate photograph. If a corresponding matched point is located, where $f(\Delta D)'$ is the first absolute maximum along this range, it is accepted as a matched point and tagged a "measured" point; if not, the predicted elevation $\bar{h}_{x,y}$ is accepted as the correct elevation. In either case, the derived elevation is tagged to indicate whether it is a predicted elevation. The predictive process is then repeated in its entirety with the next $N \times M$ area in the rectified "$x$" direction. A further opening of search limits ($r$) then takes place when the predicted parallax is above the approximate mid-elevation level in the model. In steep terrain, whenever the last "measured" point in the $x$ direction, $h(1)$, of Figure 12 is a predicted value, the range opens to a larger selected value.

The next program section is for contouring the elevations determined by the predictive process. This routine initially corrects each predicted point for relief displacement. These ortho-corrected elevation points are distributed over the entire photograph at about 0.090 inch for an $N \times M$ area of $36 \times 36$ spots. The program then interpolates between these corrected matched points to produce an elevation for each corner point (nearest the nadir point) of a $6 \times 6$ spot area. The elevation values are then given their appropriate contour designations which are examined to determine where the contour lines should be placed. A contour line, appropriate in width to the five sizes used, is placed in the $6 \times 6$ spot area that contains a contour interval change. (Other stored symbols can be entered at this point.) The formed contour lines can then be transferred to magnetic tape and printed by the scanner-printer as a contour manuscript.

*Direct Orthophoto Program*

When the $x$, $y$ tabulations of point elevations are made for relief distortion shifts, the amount of displacement involved is recorded as an amount in $x$ and $y$ shift. Both the unortho-corrected $x$, $y$ point coordinates and the ortho-corrected $x''$, $y''$ coordinates are stored in table format. The vector distance between these two points represents the ortho-displacement. The displacements are then converted to a shift list which specifies the displacement required to move each picture element in the prime photograph to its new ortho-corrected position. The list-generating routines indicate where in the photograph a need exists to extract or insert photo points (i.e., photo detail) and where photo data is to be re-positioned. (When ortho-correcting unrectified photographs, corrections for the tilt and scale distortion determined from resection and orientation would be combined with the relief displacement due to ortho-correction to produce an orthophoto map.)

In using this shift list, the photographic data are now processed one scan at a time, and the necessary set of spot corrections in $x$ and then in $y$ are made. The ortho-correction program computes the $x$ and $y$ vector shifts of the radial relief displacement vector of a point ($\overline{\Delta r} = \bar{r}xh/p\text{-}h$) at rectified photo-scale and then corrects for datum-scale. "$p$" is the principal distance of the point from the nadir (more exactly the isocenter), and "$h$" is the elevation of photo scale. By compressing or expanding the data a point at a time, the best quality of an orthophoto is obtainable. These data are then stored on tape for printout of an orthophoto.

(*See Summary on the following page.*)

## CONCLUSIONS

The Digital Automatic Map Compilation System has produced maps and orthophotos of sufficient accuracy ($C$-Factor greater than 250) by one system and sufficient speed per model (less than 60 minutes) by a second system unquestionably to prove technical feasibility for producing maps and orthophotos by digital techniques.

It is apparent that the precision, resolution, and compilation speed of the present photodigitizer and computer system can be improved through refinements and redesign which are within the state of the art.

The anticipated goals are a $C$-Factor of 1500 and 1 to 2 hours per model of data processing time. Based on extensive experimentation and planning, it is concluded that these goals are realistic.

A digital mapping system that is economically justifiable, as well as technically feasible, can be developed within the next several years, as an extension of this project.

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SUMMARY OF DAMC SYSTEM COMPONENT TEST

| *Component* | *Functional Requirement* | *Performance* | *How Obtained* |
|---|---|---|---|
| Photo-digitizer | Model Area (half section) | $4\frac{1}{2}'' \times 4\frac{1}{2}''$ | WILD Stereocomparator |
| | Traverse Speed | 0.9 inch/min | Stereocomparator |
| | Point Measurement Error | 2 micron (rmse) | Stereocomparator |
| | Scan Time (4.5″×4.5″) | 5 minutes | Automated |
| | Digitizing Range | 8 shades | Scan Mode |
| | | 64 shades | Record Mode |
| | Density Range | 0.04–0.80 | CRT-PMT Scan |
| | Spot Positional Accuracy | 92% within $\frac{1}{2}$ spot | *Y*-line |
| | | 68% within 1 spot | *X*-scan |
| | Spot Interval | 2.5 mil | *X* and *Y* |
| | Signal-Noise Ratio | 40:1 | Electronically |
| | | 25:1 | Optically |
| Photomap Printer | Printing Time (4.5″×4.5″) | 5 minutes | Automated WILD scan |
| | Contour Line Widths | 5–15 mils (2.5 mil spots) | Computer generates data |
| | Tic Mark Widths | 7.5 mils | Computer generates data |
| | Tic Mark and Symbol Location | ±5 mils | Computer generates data |
| | Output Scale to Photo Scale Change | ±10% | Computer program |
| Computer System | General-Purpose Digital Computer | 32,000 words (36 bits) | IBM 7094 |
| | Processing Times Contours and | 58 minutes | DAMC System (Predictive) |
| | Orthophoto (4.5″×9″ model) | 137 minutes | DAMC System (Sequential) |
| | C-Factor (ASP) | 250 | DAMC System (Predictive) |
| | | 180 | DAMC System (Sequential) |
| | Horizontal Error | 0.02″ | DAMC Systems |

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