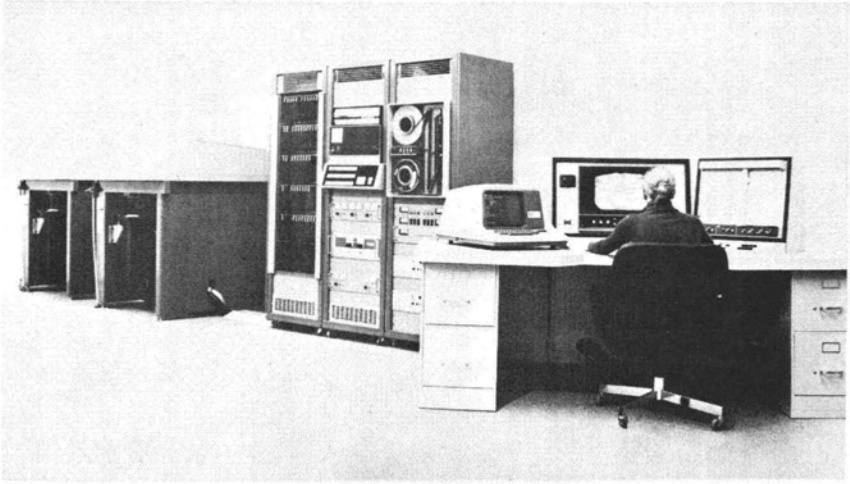

FRONTISPIECE. GPM-II. The scanners are at the left and the correlator and system computer are in the three cabinets at the center: the operator is seated at the console.

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The Gestalt Photomapping System

The Gestalt Photomapping System features automatic correlation and automated off-line processing of digital terrain models (DTM).

(Abstract on next page)

INTRODUCTION

THE GPM II IS IN principle an analytical plotter: photo coordinates are transformed into model coordinates according to the results of a least-squares solution to interior, relative, and absolute orientation. Like a stereo-plotter orthophoto-printer combination, the GPM produces contours and orthophotos. Unlike conventional analytical instruments, the GPM operates with little or no operator assistance after orientation.

Differential rectification in the GPM is accomplished by the Gestalt Correlator. The correlator digitizes 9 × 8 mm areas of each diapositive and measures parallaxes for 2444 points within that area. Models are completed by the successive processing of individual patches. The GPM is unique in three ways:

(1) complete differential rectification occurs over almost a square centimeter rather than only at the floating mark;
(2) this rectification is performed by a special-purpose hardwired computer in less than a second; and

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(3) over 700,000 heights measured by the correlator for each model are written on magnetic tape to form a digital model of the terrain (see Figure 1) ideal for computer processing.

Operation

Stereomodels are prepared for the GPM by measuring the photo coordinates of control points and entering their locations together with other model parameters (Table 1) on either punched-paper or magnetic tape.

After preparation, the model diapositives are loaded into the left and right scanners; a paper print is placed in the *XY* recorder for reference; model parameters are read by the system computer; a tape is loaded into the DTM transport; and film is loaded into the printer.

Interior orientation consists of locating eight fiducial marks under the crosshair on the TV monitor. Relative orientation requires the removal of parallax from at least five and preferably six arbitrary points on the model. Absolute orientation is accomplished by simultaneously locating three to eight homologous control points under the crosshair. Each point is positioned near the crosshair by the computer: the operator then moves the point under the crosshair with handwheels. Point location is facilitated by 20-times magnification on the monitor.

After point location, the system computer completes an iterative least-squares adjustment of the linearized orientation equations in about three seconds and prints the resulting orientation parameters (Table 2) on the computer terminal. The operator may accept or reject the orientation, remensurate relative or absolute points with excessive errors, or delete absolute points which cannot be located accurately.

Once the orientation has been accepted, spot heights may be measured and specified locations (grid intersections, etc.) automatically marked on the photographic output. When these optional operations are complete, the operator releases the GPM to process the model automatically.

Output

The GPM produces one DTM tape and one photo (see Table 3 for photo options) per printer. Contours (Figure 2) and slope maps (Figure 3) may be drawn off-line at any scale, with or without smoothing and annotation, on the GPM Plotting System.

GPM contour sheets differ from conventional map manuscripts in one important respect: they contain only topographic information. Planimetric details (roads, buildings, etc.) are not reproducible from the DTM data base which is used for both photographic and plotted contours. This information is, of course, readily available from the orthophoto which is produced with the DTM and may be added directly to the plotted contour sheet by conventional means.

Contours plotted from the DTM are usually drawn at the scale of the final map sheet. Smoothed and annotated contour sheets with grid intersections may be used without

Abstract: *The Gestalt PhotoMapping System is made up of the GPM II and the GPM Plotting System.*

The GPM II is a computer-controlled, auto-correlating, analytical photomapper. It is composed of two scanners, an automatic image correlator, a control computer, an operator's console, and one or two printers. A typical stereomodel is completed automatically in less than an hour and a half after a 10 minute operator-assisted analytical orientation. Principal topographic output consists of a 700,000-point digital terrain model (DTM) on magnetic tape: planimetric output consists of an orthophoto on 20 × 25 cm stable-base film.

The GPM Plotting System is an off-line automatic DTM processing system. It consists of a disk-based minicomputer and plotter. Smoothed contours and slope maps may be plotted at map scale with annotation in less than an hour and a half. A GPM III orthophoto and GPM Plotting System contours may be combined without editing by using conventional photographic techniques to produce a reproduction-quality contoured orthophoto map in less than a day.

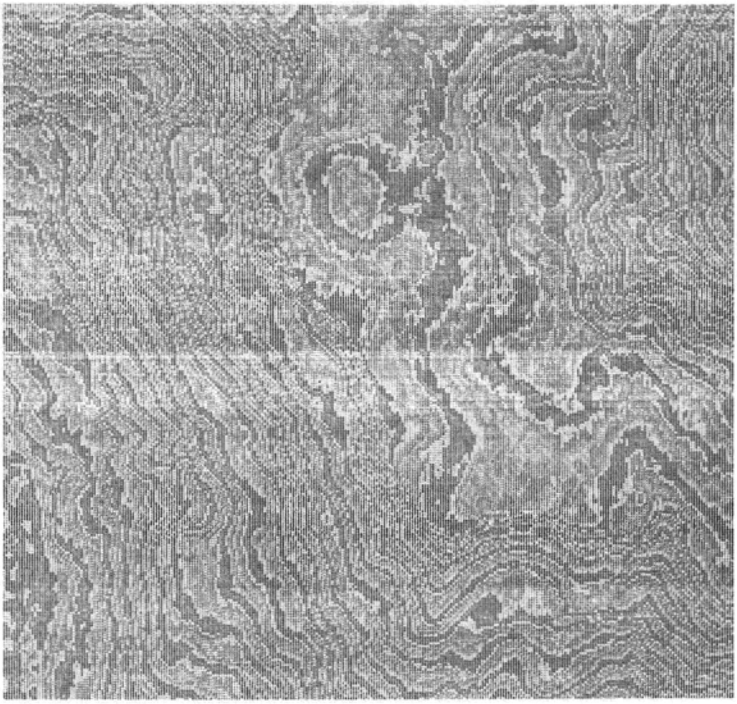

FIG. 1. Graphic representation of a GPM II digital terrain model. Each number represents the meter digit of a measured height.

further editing to overlay a screened map-size orthonegative in plate making. Thus it is possible to produce a contoured and annotated orthophoto map with only one intermediate photographic operation: enlarging and screening the GPM Orthophoto (Figure 4).*

Output of lesser quality may be obtained almost instantly. A contoured stereo-orthophoto pair could be used for road-building/resource-development purposes where commercial map production is not an object (Figure 5).

Stereo-orthophoto maps may be made from GPM ortho-stereomate pairs with or without plotted contours (Figure 6).

Accuracy

The overall accuracy of the Gestalt Transformation may be checked automatically by comparing DTM elevations with any number of model control points on the plotting system computer. Recent results for a series of nine consecutive trials using 94 control points each on the National Research Council of Canada Sudbury Test Area 1:16,000 model gave a mean RMS height error of 0.022 percent of flying altitude.

Orthophoto planimetric accuracies measured by Blachut and van Wijk[1] gave RMS errors of 27 micrometers radial and 18 micrometers tangential for a total of 497 points on two orthophotos of the National Research Council Ripon Test area.

Sixty-six heights derived from three ortho-stereomate pairs had mean RMS errors of less than 0.03 percent of flying altitude.[2] Of note is that half the points were derived from a model with relief in excess of 20 percent of flight altitude (see Figure 6).

Manual spot heighting after orientation produced RMS errors of 12 micrometers in X, 17 micrometers in Y, and 20 micrometers in Z for 229 points measured on seven models with six orientations.

Theory of Operation

The elegant mechanical and optical simplicity of an analytical plotter is a direct consequence of the application of digital computing techniques to transform the parallax measured by the photogrammetrist into the true height of the point under the

* The contours reproduced in this article were drawn with a ballpoint pen, copied with a 4 × 5 inch camera at a reduction of 10 times, then enlarged 3 times: their quality would be expected to improve in a production environment.

TABLE 1. MODEL PARAMETERS AND OPTIONS

MODEL IDENTIFICATION	OUTPUT PARAMETERS
	DTM Label
	DTM Units
	Contour Interval
DIAPOSITIVE SPECIFICATIONS	Contour Units
Emulsion or Base	Print from Left or Right Photo
Corner or Side Fiducials	Contours or Stereomate
Maximum Density	Superimpose Contours?
MODEL SPECIFICATIONS	CONTROL
Camera Focal Length	5 or 6 Relative Points?
Nominal Base	Match Relative to nearest Absolute Point?
Control in Feet or Meters	2 to 8 X and Y Coordinates
Scale	3 to 8 Heights
Start and Finish Coordinates	
Difficulty (Mask Size)	
OPTIONS	
Earth Radius Correction	
Lens Correction Coefficients	
Atmospheric Refraction Correction	

floating mark. Since the mathematics can be arbitrarily accurate, the accuracy of the plotter reduces to the precision to which its stages can be located and the ability of the operator to detect and remove parallax.

Analytical plotters may be used to follow contours or profile, but the action, so to speak, is always at the floating mark: the remainder of the field of view is useful only to help the operator guide the floating mark.

In the GPM, the results of the analytical orientation are applied to the center of each of the 1000 or so patches which are assembled to make a complete model. Since the orientation parameters are exact only at the patch center, only that portion of the patch where the approximation is excellent is used for output. Within each patch, the Gestalt Correlator measures the height of 2444 points: in effect each of these points is a floating mark about which the correlator senses and removes parallax. Parallax is effectively removed from the entire patch since (1) the points are only 182 micrometers apart, (2) they are regularly distributed over the patch (47×52 matrix) in model coordinates, and (3) intermediate areas are smoothed to produce a best fit for the 2444 points.

In an analytical plotter, parallax is re-

TABLE 2. ORIENTATION PARAMETERS AND OPTIONS AVAILABLE AFTER ORIENTATION

RELATIVE ORIENTATION Y RMS ERRORS
- Accept Relative Orientation (Yes or No)

ABSOLUTE ORIENTATION X, Y, AND Z RMS ERRORS
- Accept Absolute Orientation (Yes or No)
- Delete or Remensurate Points (Yes or No)

SPOT HEIGHTS (Optional)

MARK SPECIFIED LOCATIONS ON PHOTO OUTPUT (Optional)

SCAN IN GROUND COORDINATES (Yes or No)

MODEL PARAMETERS
- Control Point Coordinates (Model and Ground Coordinates)
- Model Kappa
- Model Scale
- Model B, B_y, B_z
- Model X_o, Y_o, Z_o
- Left Photo Phi, Omega, Kappa
- Right Photo Phi, Omega, Kappa
- Number of Absolute Orientation Control Points Used

TABLE 3. GPM OUTPUT

PHOTOGRAPHIC	
Orthophoto:	Orthophotos are printed on 20 × 25 cm stable-base blue-sensitive film at specified scale from either left or right diapositive. Orientation data (Table 2) is printed on the outside margin of the film. Control points and specified locations may be marked.
Stereomate:	The stereomate is similar to the orthophoto except that the other member of the stereo pair is printed with specified parallax restored.
Contours:	Photographic contour overlays may be printed on the same film as the orthophoto, or on high-contrast ortho-sensitive film. Contours are drawn at specified intervals with up-slope and down-slope coding and index contour high-lighting. Optional data includes patch maximum or center height and one spot height. Either stereo or orthographic contours may be printed.
Superimposed Contours:	Contour information may be printed directly on the orthophoto and stereomate instead of on a separate overlay.
DTM	DTM's are written on 9-track, 800 BPI magnetic tape. Each model tape contains all orientation information (Table 2). Data is recorded in patches. Each patch record contains the patch location in the model (row and column), patch origin in model and ground coordinates, and patch center in model coordinates. Patch heights are located on a 182 micrometer grid within the patch: since the grid is square in map coordinates, each height may be addressed at a ground coordinate location.
PLOTTED	
Contours and Slope Maps:	Contours and Slope maps may be plotted from the DTM with or without smoothing and annotation at any scale. The maximum size depends only on the size of the plotter: the quality of the output depends on the pen/scribing head used.

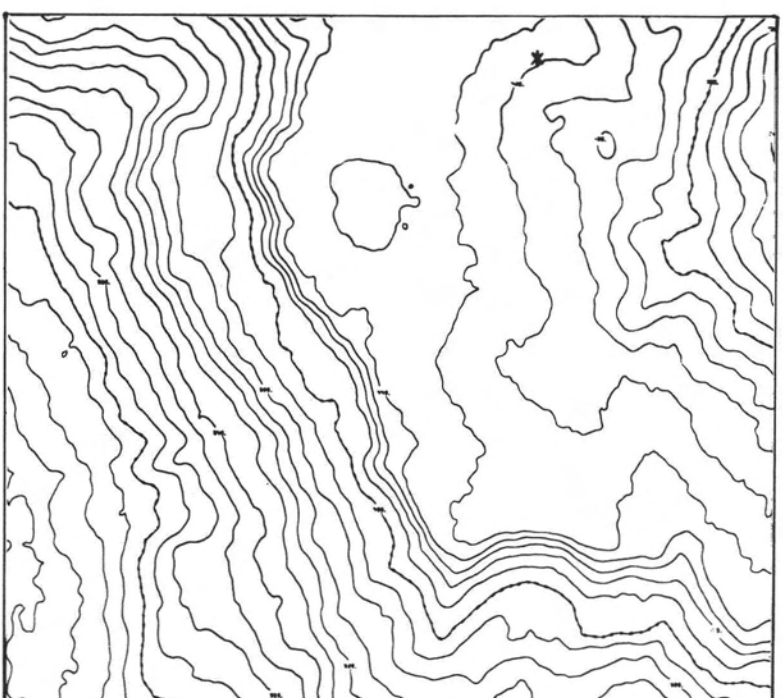

FIG. 2. GPM plotting system contours plotted from the DTM in Figure 1. Contours are in meters.

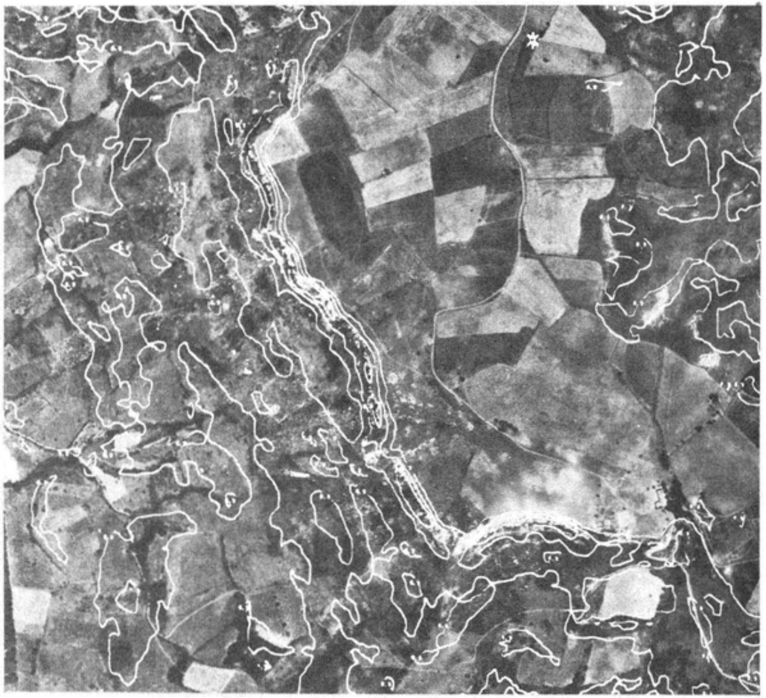

FIG. 3. GPM plotting system slope map plotted from the DTM in Figure 1. Slopes are in tangents.

FIG. 4. GPM II orthophoto with plotted contours. This orthophoto is a 2.3-times enlargement of a portion of a GPM orthonegative (reproduced herein at 0.75×). Differential rectification is based on a matrix of points with the same spatial frequency as the numbers in the DTM in Figure 1.

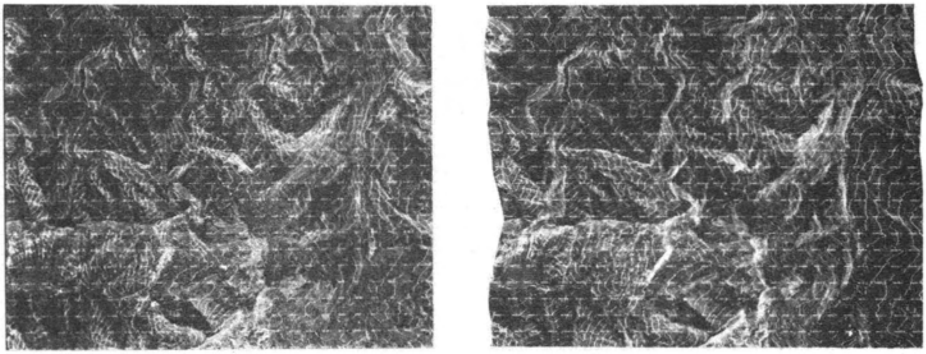

FIG. 5. GPM II orthophoto (left) and stereomate (right) with superimposed on-line contours. This orthophoto is reproduced at one-half model scale. Each number is the center height of one patch.

moved by relative movement of the plotter stages: in the GPM, parallax is removed by modifying the scanning pattern electronically to shift the locations of the 2444 patch points on the CRT face relative to the diapositive. A human operator depends on skill and experience to guide the stages: the GPM depends on repetitive measurement of parallax followed by changes to the scanning pattern to remove measured parallax. Successive iterations of measurement and correction reduce parallax till the system computer determines that correlation is complete.

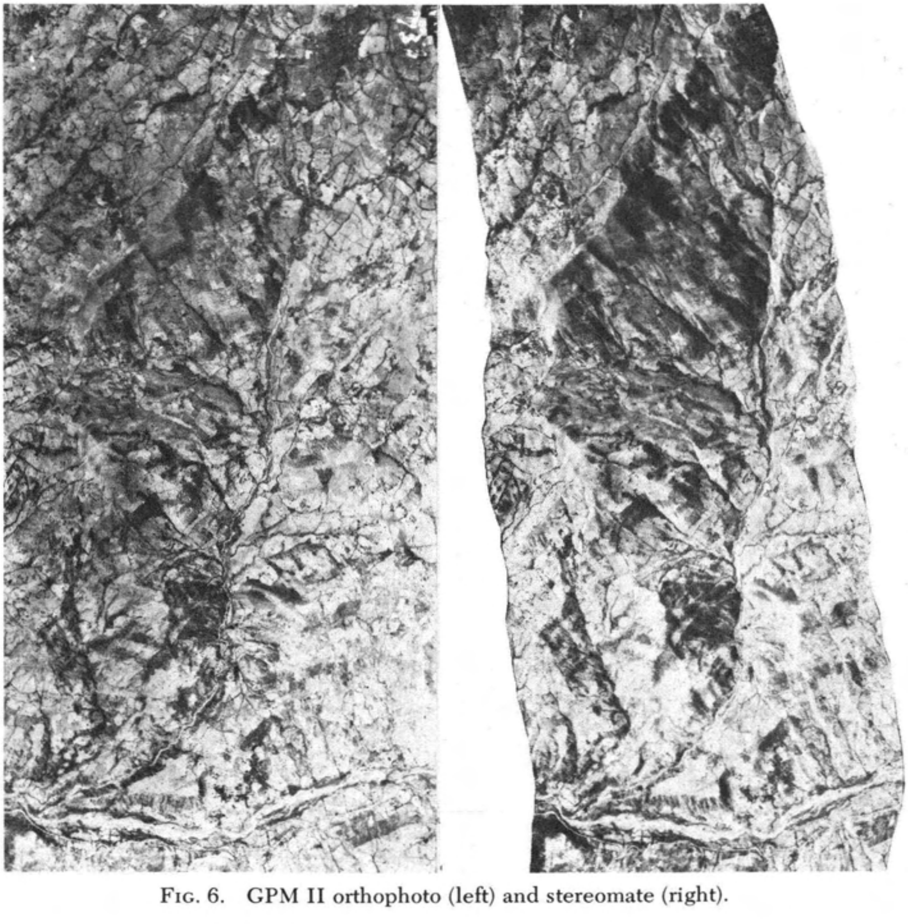

FIG. 6. GPM II orthophoto (left) and stereomate (right).

Scanning

The left and right diapositives are positioned in the two scanners by the system computer so that homologous areas are scanned simultaneously (see Figure 7). Each area is scanned by a spot moving over the phosphor of a precision CRT in a linearity-corrected rectangular TV raster pattern. The 67 × 63 mm scanning pattern is focused onto a 9 × 8 mm area of the diapositive.

A synchronized video signal corrected for system gamma and CRT phosphor noise is developed by a photomultiplier tube positioned over the scanned area. Scale and kappa-rotation corrections are effected by electronically changing the size and orientation of the scanning pattern according to parameters derived from the orientation.

After scale and rotation corrections have been made to the scanning patterns of both scanners, the video representations of the two patches are identical except for parallax due to height. To the operator viewing the patch on the TV monitor, the parallax appears as objects jumping as the left and right diapositive are alternately displayed. To the correlator, the parallax appears as phase shifts between the two video signals.

Correlation

Auto-correlation in the GPM involves:

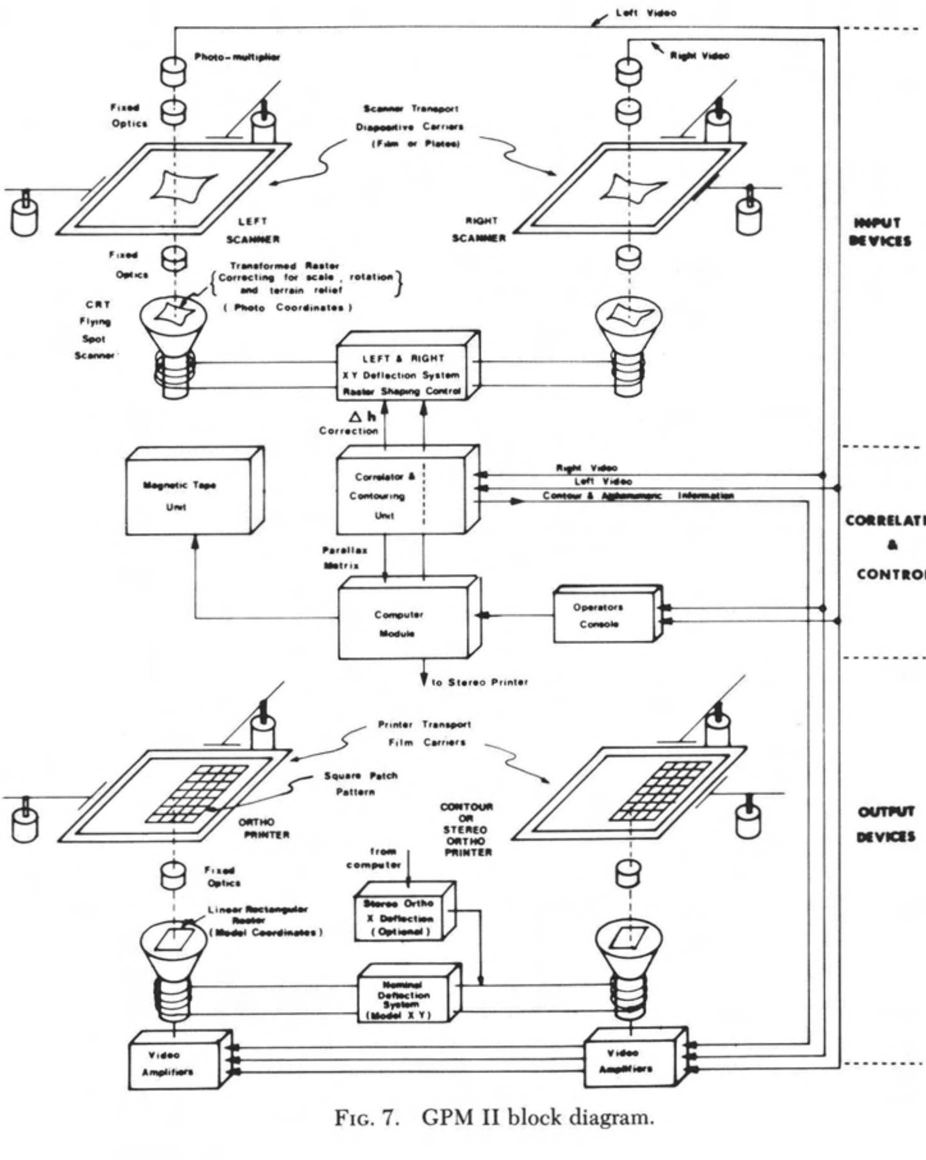

Fig. 7. GPM II block diagram.

(1) analyzing and digitizing the video from the scanners;
(2) measuring parallax;
(3) storing and smoothing the parallax data;
(4) calculating the required changes to the video scanning and applying them to the scanners; and
(5) repeating steps 1 through 4 until correlation is complete.

Because of the uniqueness of the Gestalt Correlator, these steps are discussed in detail below.

ANALYSIS AND DIGITIZATION

In the correlator the video signal from each scanner is filtered into six frequency channels, each of which responds to different rates of change in the magnitude of the video signal. The lowest frequency channel detects relatively slow variations in video level occurring over scan distances of about 2mm at photo scale. The center frequency of the next channel is double that of the first; the third channel's frequency is double that of the second; and so on. The highest frequency channel is sensitive to abrupt transitions in video over about 50 micrometers. The process is similar to Fourier analysis in that the signal is analyzed into harmonic frequency terms, each of which is assigned a coefficient equal to the number of video level changes detected by the channel of corresponding frequency.

PARALLAX MEASUREMENT

Separate parallax measurements are made for each of the six channels by cross-correlating the digital coefficients generated by the video-to-digital converter. Nearly 80,000 binary cross-correlation products are calculated for every scan of both patches. The signed magnitude of these products is proportional to the phase separation of similar video patterns from the two diapositives. These products are grouped and summed to form 2444 12-bit numbers, each of which represents the parallax detected for homologous areas on the left and right diapositives.

STORAGE AND SMOOTHING

The parallax values for each point are entered into a serial memory as the points are scanned and their parallaxes calculated. The memory serves two functions: first, it stores the parallax value for a point till the point is scanned again; second, it sets limits on the maximum change which may occur between adjacent points. The latter function filters out aberrations and ensures that the correlator's digital representation of the model will, like the ground, be continuous.

DIFFERENTIAL RECTIFICATION

Video parallax measured during one scan is reduced in the following scan by shifting the coordinates of each of the 2444 points by an amount proportional to the detected parallax. The four constants of proportionality (left x and y; right x and y) are derived from the analytic orientation by the system computer and applied to the parallax by hardware multipliers. The resulting numbers are converted to analog signals and applied to reshape the scanning patterns and, thus, the positions of the 2444 points.

ITERATION

The process of scanning, analysis and digitizing, parallax measurement, storage and smoothing, and differential rectification repeats about 50 times per second. On successive iterations each of the 2444 parallax values is changed in response to any remaining parallax. When no further parallax is detected, correlation is complete. Watched on the TV monitor, the earth literally comes alive as the distortions imposed by the photographic process are removed and the alternating images from the two scanners merge into one.

OUTPUT

The system computer constantly monitors selected data points within the patch. When the parallax values for these points stabilize, the computer stops input to the correlator and compares areas of the patch just correlated with overlapping areas of previous patches. If the patches are correctly matched, the computer reads the parallax values in the serial memory, converts them into ground heights, and writes them on magnetic tape along with patch X Y coordinates. Photographic output is produced simultaneously by the printer. An orthophoto patch is printed by projecting the rectified raster from a linearity-corrected precision CRT onto film. If a stereomate is to be printed, the rectified raster has a specified amount of parallax restored before printing. Contours may be generated on-line by creating a video pulse whenever the parallax crosses a threshold calculated by the system computer for a specified contour interval. Contours and other information may be printed on a separate overlay or superimposed on the orthophoto or stereomate. When the output for one patch is complete,

TABLE 4. AVERAGE TIME AND FREQUENCY OF MAINTENANCE REQUIRED FOR ONE YEAR'S OPERATION OF GPM II-2

	TESTING		RECALIBRATION		TROUBLESHOOTING	
	Time	Personnel	Time	Personnel	Time	Personnel
Digital Electronics (Correlator)	½ hr/mo	Operator	None	Engineer	8 hr/6 mo	Engineer
Digital Electronics (Motor Control)	None	Technician	None	Engineer	2 hr/3 mo	Technician
Analog Electronics (Geometric)	½ hr/wk	Technician	½ hr/wk	Technician	4 hr/6 mo	Engineer
Analog Electronics (Cosmetic)	5 min/day	Technician	2 hr/wk*	Technician	6 hr/6 mo	Engineer
	CLEANING		REALIGNMENT			
	Time	Personnel	Time	Personnel		
Mechanical	2 hr/wk	Technician	4 hr/6 mo	Technician		
Optical	None	Technician	None	Engineer		

* This time is comprised of approximately 15 minutes per week for routine calibration checks, and several hours to obtain a satisfactory output density range when a new job is set up with different input material. In addition, 20 hours per month were devoted to improving the density matching of adjacent models and other video cosmetics.

all scanner and printer transports are moved in model coordinates to the next patch by the system computer. A 20 percent to 50 percent overlap is allowed between patches to ensure accurate, well-matched output: the duplicated area is excluded from the DTM by the system computer and from photographic output by electronically masking the printer CRT's.

MAINTENANCE AND RELIABILITY

The GPM may be divided into mechanics, optics, and digital and analog electronics. Mechanical maintenance is straightforward and consists of keeping the scanner and printer moving parts clean. Optically, the GPM is extremely simple and sturdy.

The GPM Digital Correlator is quite reliable. Detailed diagnostic programs check all major subsystems and correlator memory automatically.

The analog electronics consists essentially of two extremely accurate closed-circuit television systems. Although the circuits have been designed with stability as a prime consideration, drifting is inherent in analog circuits and weekly testing is required. Analog calibrations may be divided into two categories: those which affect the accuracy of the system (geometric) and those which affect the appearance of the orthophoto (cosmetic).

GPM II-2, the first commercial series II photomapper, has been operating on an average of 18 hours daily, five days a week in a government mapping organization for one year. Table 4 summarizes the maintenance requirements for that instrument.

GPM PLOTTING SYSTEM

The GPM Plotting System was designed specifically to process high-density DTM's. The prototype system consists of a Data General Nova 840 with 40K of core, an IBM-compatible tape transport, a 10-megabyte disk, and a plotter. The system is Fortran programmable to simplify user adaptation of plotting algorithms. Current software requires about 15 minutes to process a DTM and generate plotting instructions: plotting takes about an hour. An example of smoothed and annotated contours is shown in Figure 2. Because of the density of the data base, interpolation between measured heights is extremely simple, even on steep slopes.

CONTINUING DEVELOPMENT

Two principal projects nearing completion will improve the accuracy and usefulness of the GPM System. Scanner transport positioning accuracy is being improved to 5 micrometers by replacing the racks and stepping-motor-driven pinions with servo-motor-driven lead screws. GPM Plotting System software development should soon make it possible to merge DTM's to form digital models for large areas: such models will ultimately be referenced by computers much as maps are by men.

CONCLUSION

The GPM II System represents the current state of the art in automated mapping equipment. Its use is not, however, limited to the laboratory: in addition to the three-year-old prototype now at Gestalt's plant in Stittsville, Ontario, a GPM II has been in continuous operation at the U.S. Geological Survey in Reston, Virginia since June of 1976; a GPM II is currently being installed at the Department of Energy, Mines and Resources in Ottawa; and a GPM System will be delivered to the Instituto Geográfico Agustin Codazzi in Bogotá within the next year.

References

1. T. J. Blachut and M. C. van Wijk, Results of the International Orthophoto Experiment 1972-76, *Photogrammetric Engineering and Remote Sensing*, Vol. XLII, No. 12, Dec. 1976.
2. M. W. Haq, *Stereo-Orthophoto Project Final Report*, DSS File No. SS05.KL009-5-0085, Contract No. 1SS5-0333, Dec. 1976.

Announcement and Call for Papers

International Symposium on Remote Sensing for Observation and Inventory of Earth Resources and the Endangered Environment

Freiburg, Federal Republic of Germany
July 2-8, 1978

Sponsored by the International Society for Photogrammetry, Commission VII, Interpretation of Data, and the International Union of Forestry Research Organizations, Subject Group 6.05, Remote Sensing.

The symposium will be open to all individuals interested in the interpretation of remotely sensed data and imagery in any field of research and and application. Papers are invited which deal with new results of fundamental or applied research or new experiences and methods in the operational application of remote sensing.

Plenary sessions, dealing with topics of general or fundamental interest, will include:

- The contribution of image interpretation for the exploration of the Earth, its resources, and environment: approaches and results;
- Suitability and applicability of computer-aided classification of remotely sensed data for practical purposes;
- Signatures of objects, methods of pattern recognition, and texture analysis;
- Identification of properties of objects and phenomena and their temporal and spatial variations by means of remote sensing; and
- Remote sensing from space: experiences from the seventies, programs for the eighties.

Working group meetings, dealing with special and detailed problems or results, will include:

- Analog and digital interpretation methods for data and imagery from airborne and space sensors;
- Spectral signatures of objects;
- Natural land resources (survey, thematic mapping, monitoring, and exploration);
- Vegetation damage;
- Environmental monitoring (wetlands, water quality, urban areas, microclimatic effects);
- Oceanography, sea and inland ice; and
- Civil engineering projects and industrial processes.

Those intending to present a paper should submit the title, and indicate to which of the topics of the plenary session and the working group meetings the paper corresponds, no later than January 31, 1978. Three hundred copies of a 200 word abstract, typed single-spaced in English, French, and German, should be submitted by March 31, 1978.

For submission of the above, and for further information, please contact:

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