*The Automatic Map Compilation System**

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ABSTRACT: *This paper describes the Automatic Map Compilation System. It uses a small digital computer to position an electronically generated scan on estimated homologous points on a pair of diapositives. The resulting signals are then correlated and used to measure the height error. The computer receives the height error and uses it to maintain the system in contact with the surface defined by the diapositives. The system moves through a series of profiling sequences to simultaneously expose a new photograph, with the imagery moved so that it will appear in correct orthographic projection in relation to a selected scale, and an altitude chart showing the contour information. A complete compilation for normal 9″×9″ vertical photography is accomplished in about $1\frac{1}{2}$ hours.*

THE Automatic Map Compilation System developed at Thompson Ramo Wooldridge under the auspices of the U. S. Army Engineer Geodesy, Intelligence and Mapping Research and Development Agency automatically produces orthographic projection photographs and altitude charts from stereo pairs of aerial transparencies. These can be combined and suitably annotated to produce a photomap of the stereo area.

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The system utilizes a small digital computer to provide the equivalent of a stereo model. Electronic scanning of small areas and correlation of the resulting signals is used to evaluate height errors. The computer controls the system through a series of profiling sequences using the height-error signal to keep the system "on the ground."

The principle of automatic height determination from aerial photographs can be visualized in terms of an analog model. The situation is diagrammed in Figure 1, where the view normal to the line of flight (projector separation) is shown. Suppose in a small portion of the field there is a high light point P. If P is estimated low at P_e it would be found to the left of its estimated position on a diapositive exposed at C and to the right of its estimated position on a diapositive exposed at C'. A synchronous scanning in the direction of the line of flight and centered at the estimated positions of the homologous points will therefore produce signals from corresponding image points that are displaced in time an amount proportional to the height error.

In the Automatic Map Compilation System, the two diapositives and a photosensitive film sheet used for printing the output are mounted on a common movable carriage as shown in Figure 2. Associated with this carriage are four flying-spot scanners, one for each diapositive, one for exposure of the orthophoto and one for exposure of the altitude chart. The traces on the diapositive scanners are imaged on the two diapositives,

* Presented at March 24–30, 1963 ASP-ACSM Convention, Hotel Shoreham, Washington, D. C.

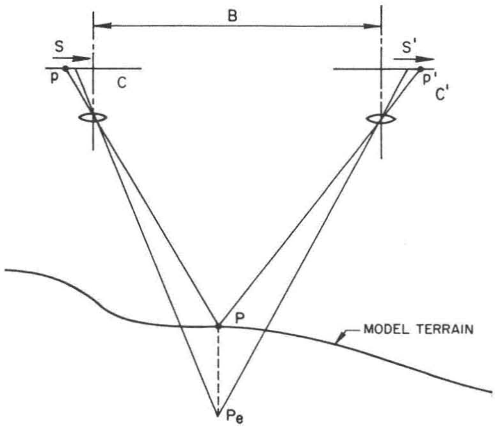

FIG. 1. Use of stereo photographs to develop height-error signal

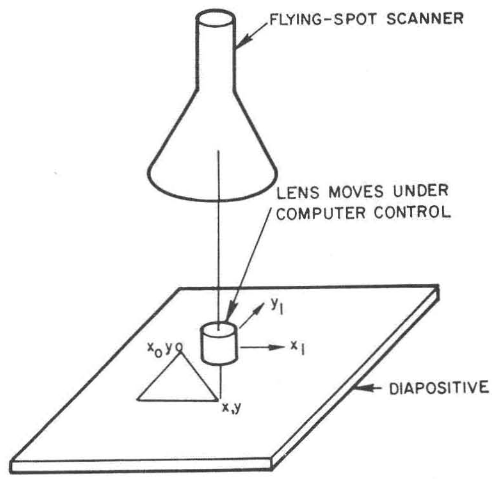

FIG. 3. Photograph scanning system.

using lenses whose positions are under the command of the computer. As shown in Figure 3, this permits the lenses to be moved to observe the computer-estimated homologous points on the two diapositives. The lenses for the orthophoto and altitude print-out are fixed in position, making the areas printed out dependent only upon the instantaneous carriage position. Conversely, the instantaneous carriage position defines the geographic coordinate under observation at a given time.

The operator is able to observe the diapositive areas being scanned at a given time through an electronic stereoviewer. This is essentially a twin TV system on which the images observed on the two diapositives are reproduced; an electronically generated crosshair is available as a reference for use in system calibration and as a floating mark.

For the present, the system operates only with diapositives whose orientation matrices are available from comparator measurements and subsequent calculations. When the diapositives are introduced into the system, the computer directs the transport carriages to move so scanning can take place near the first pass-point. The operator, through Flexowriter control of the computer, then moves the scanning, through motion of the diapositive lenses, until the selected point has been centered on the crosshair in the stereoviewer. When this has been accomplished, the operator signals the computer to take into its memory the system coordinates of the first pass-point and then to move to a second pass-points where the process is repeated. The computer then calculates new coefficients for each diapositive that are characteristic of the orientation of the diapositives in the system and of any drift in the electronics. As a check it then directs the system to move to a third pass-point, using its geographical coordinates (X, Y, Z). If this third point is well centered on the crosshair, the photo coordinates have been correctly converted to machine coordinates. The automatic compilation is then initiated.

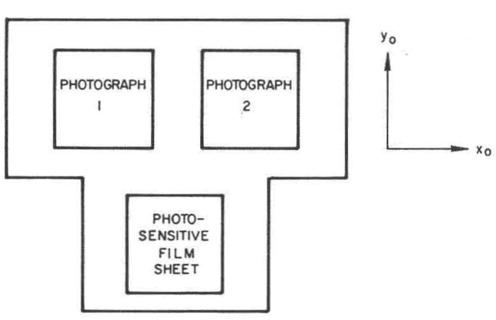

FIG. 2. Carriage configuration of automatic map compilation system.

In the starting position, the carriage is at a position $X/m=x_0$, $Y/m=y_0$ where m is the desired orthophoto scale. As pointed out earlier, the homologous points (x, y) and (x', y') on the two diapositives corresponding to the spatial point (X, Y, Z) are scanned by shifting the two lenses amounts corresponding to the differences $(x-x_0, y-y_0)$ and $(x'-x_0, y'-y_0)$. The instrument then proceeds in a profiling mode, with the carriage moving in a direction nearly perpendicular to the flight line, signaling the computer when each new 0.010″ interval has been reached. For each position the computer, with the aid of the altitude measured at preceding points, estimates the new altitude and directs the diapositive lenses to center on the corresponding homologous points. As the profiling proceeds, the height-error evaluating circuitry operates to correct the height estimate, so that the instrument can proceed without losing contact with the surface. At the same time the video signal from one of the diapositive scanners is used to create a scaled image of the area "seen" by the scanner on the flying-spot scanner associated with the orthophoto. The computer also provides a signal to the fourth flying-spot scanner, to adjust the exposure on the altitude chart appropriately to the altitude interval. Successive ranges of elevations are delineated by white, gray or black line segments in the contour interval.

At the end of each profile the carriage steps over in the x direction, typically by 0.020″, and proceeds to profile in the opposite y direction, so as to expose a new orthophoto strip and contour interval line. The process continues in this manner until the desired area has been compiled.

As profiling progresses the operator watches the stereoviewer and the height-error signals reported to the computer as reproduced in lights on the control panel. As long as the instrument maintains contact with the stereo surface the operator can relax. However, if contact is lost, as evidenced either by the stereo image mismatch or by a "lack of correlation" light or erratic behavior of the error lights, the operator stops the profiling operation and then, through the Flexowriter U (for up) or D (for down) keys, modifies the height as it appears in the computer memory until the stereo image appears in the plane of the crosshairs. The automatic profiling operation is then re-initiated.

Figure 4 shows an orthophoto and altitude chart made by the machine. The photography was vertical from an altitude of 10,000 feet. The contour interval shown is 10 meters. The automatic profiling was accomplished in about an hour and twenty minutes including three manual interventions. It will be observed that the "noise" on the contour lines is

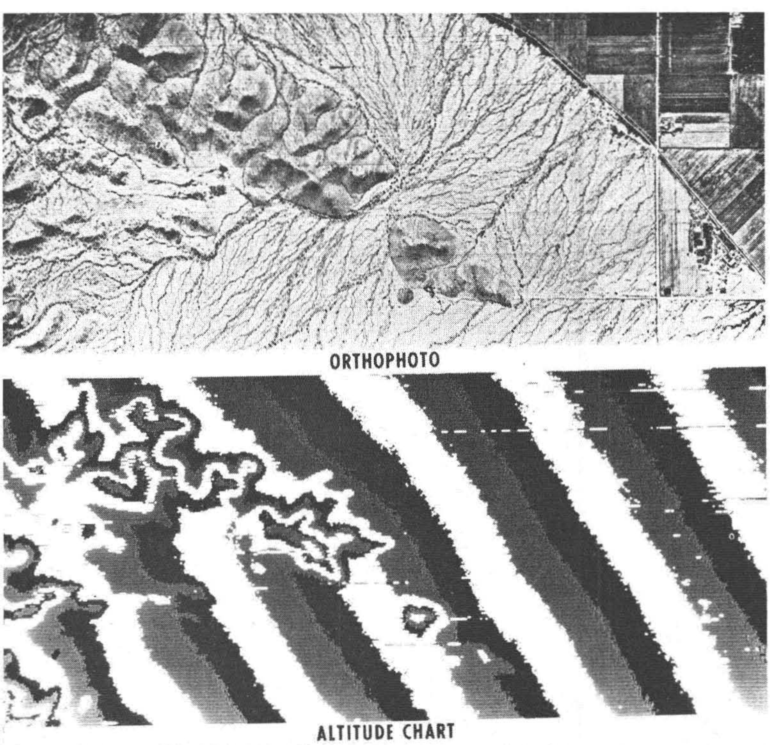

FIG. 4. Altitude chart and orthophoto.

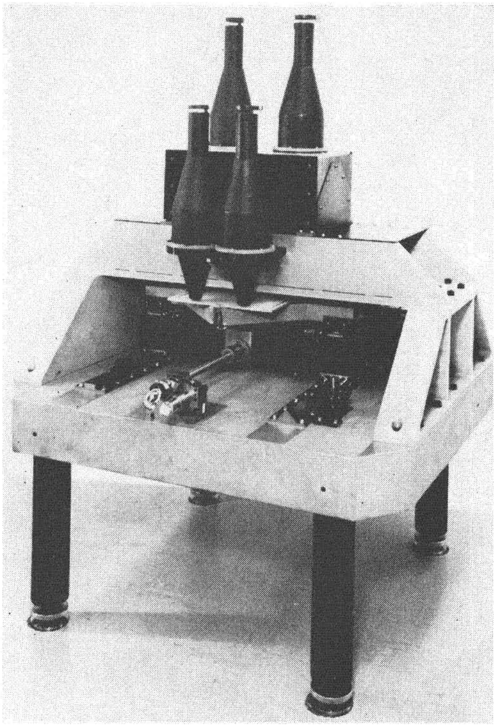

FIG. 5. Automatic map compilaton mechanical assembly.

primarily a "bouncing," indicating that the basic internal sensitivity of the system was in excess of a "least count" of 0.001″ at the scale of 1:20,000—that is, the smallest detectable height sensitivity was within 20″ on the ground.

The present map compilation instrument is an experimental machine intended to provide verification of the fundamental concept. The basic instrument is shown in Figure 5, and the control panel and stereoviewer are shown in Figure 6.

Operation of the equipment involves a number of subtle techniques. These are described briefly in the following sections. The diapositive carriage moves smoothly during the profiling operation. This makes it necessary to use "stop motion" circuitry, analogous to the image motion compensation system in a camera. This allows scanning to center accurately at the points specified by the computer despite the carriage motion.

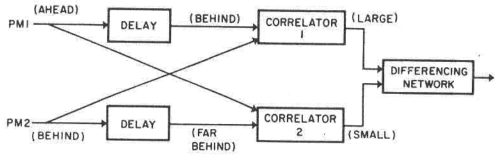

FIG. 7. Height-error sensor. (Parenthetical notation for displaced scan.)

The computer commands the lens servos through precision digital-to-analog converters. Since the point-by-point measurements proceed at a rapid rate—about fifty times per second for the present operation—any delay in the servos' achieving the designated positions would interfere with the operation. For this reason the instantaneous servo error signal is applied to the flying-spot scanners with appropriate gain to cause the scanning to move over precisely the correct amount to compensate for the servo error. The system, therefore, operates with an essentially instantaneous servo response.

Immediately following a new command from the computer, scanning is initiated over the designated areas on the diapositives. The resulting signals are applied to a pair of correlators through complementarily connected delay lines as shown in Figure 7. The correlators act to produce a maximum output for inputs that are coincident in time, with reduced out-

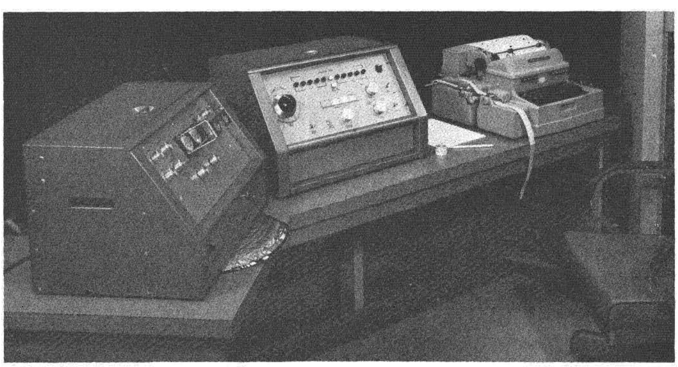

FIG. 6. Control panel and stereoviewer.

puts when the signals are displaced in time. The result is to have outputs from the two correlators that are equal for coincident signals, while one increases for time displacements in one direction (say, positive height errors), the other increases for time displacements in the opposite direction (negative height errors). The difference between these two signals becomes a measure of the height error.

The height error is applied to a height error measuring unit shown in outline form in Figure 8. The error is integrated and the output of the integrator used to control a pair of threshold circuits, one acting on positive errors, the other on negative errors. If one of the threshold values is exceeded, the reversible counter is stepped in an appropriate direction and the integrator restored to zero output. Associated with the counter is a digital-to-analog converter whose output is used to shift one of the diapositive scans in the X direction. At the beginning of a new measurement cycle, the counter and integrator are reset to zero by computer command. As scanning progresses, any observed error will step the counter and introduce a correction signal. As scanning continues any additional error will cause the operation to be repeated until equilibrium is reached. The computer then takes the count, indicative of the required height correction, into its memory, and uses it to update its information so that it can maintain contact with the surface. There is thus an independent height measurement at each stationary point in the operation. This is currently made every 0.010″ of travel in the y direction.

At each measurement point an area of 0.050″×0.050″ at the orthophoto scale is examined. The diapositive scans are adjusted under computer control to an area appropriate to the local scale, larger for points at high altitude and smaller for points at low altitude. The orthophoto exposure is limited by video switching techniques to provide a nonoverlapping printout.

It is expected that the diapositive scanning will be modified in the near future so that it conforms more nearly with the orthophoto

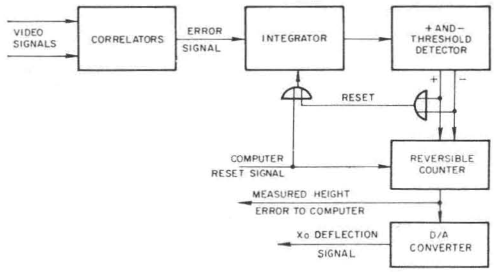

FIG. 8. Height-error measuring unit.

scanning. This will require the distortion of the otherwise square scan to a parallelogram whose precise shape is a function of the slope of the terrain element being examined and of its position relative to the camera. The signals required to control this operation are readily obtained by additional correlation circuitry combined with appropriate video switching techniques.

The Automatic Map Compilation System uses rather conventional electronic, servo and optical elements to achieve a system that is faster operating and more flexible than any similar instrument. Its potential accuracy is limited only by the measuring techniques used and the stability of its various components. Its sensitivity with good imagery is comparable to that of a good operator; with poor imagery, it probably is better. The system cannot, however, work unattended. Occasional manual intervention is necessary to start the operation and to assist the instrument over areas that are unsuited to automatic operation. These include steep cliffs where imagery at the two levels cannot be simultaneously in the field of the correlators, hidden areas in one or both photographs, and areas of such low image detail as to provide no useful height signals. In such cases, the operator, through his larger view of the area, is able to interpolate useful information to keep the system going.

Achievement of a working system required a team effort. The contributions of George Miller, mechanical engineer, Glen Kimball in electronic design, and Jules Mersel in computer programming were particularly significant.