eliminating affine film shrinkage and thus obtaining an additional, methodical increase in accuracy.

3) With values from 48 to 210 mm., the *focal-length range* is unequalled. 136° ultra-wide-angle photography can therefore be plotted just as well as long-focus normal-angle photography.
4) The instrument is contained in a completely closed housing, so that it presents maximum *resistance against ambient influences*, including fluctuations of temperature.
5) The Supragraph offers a maximum of *convenience*, because all operations including the setting of focal-lengths, the exchange of measuring marks, etc., as well as all commutations, can be easily made from the operator's seat.

Precision counters make it possible to *exactly set orientation values*, thus facilitating the orientation process.

Limit switches with indicators avoid overrunning at the limits of the working ranges and indicate the final position achieved.

It is believed that the new Zeiss Supragraph will be another important step forward on the way to photogrammetric progress.

*Automatic Map Compilation**

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ABSTRACT: *A discussion of research and development resulting in a successful prototype model of an optical-electronic system that can be added to existing conventional plotters to produce both altitude information and orthophotos automatically from pairs of aerial photographs.*

EARLY in 1960, Ramo Wooldridge was awarded a contract to produce a prototype system for the automatic production of altitude data and orthophotos from a stereomodel as projected on a Kelsh plotter. Some months later RW was awarded a second contract to develop a breadboard model of an advance compilation system intended to be faster, more versatile, and more precise than might be expected by simply adding automatic features to an existing plotting instrument. Both systems are being developed for the Army Geodesy Intelligence Mapping Research and Development Agency. The feasibility of both systems has been demonstrated, and they are now in the final stage of checkout and test. This paper describes the first system in some detail and touches on some of the salient features of the second. It is expected that the second system will be described in more detail in a later paper.

Both systems are the outgrowth of a number of programs carried on over the past ten years. The Automatic Stereomapping System attached to a Kelsh plotter will automatically produce altitude information by following the stereo-image along profile lines while simultaneously printing out an orthophoto. The Map Compilation System produces the same type of information from stereo-pairs without an optical model.

The basic principle of automatic height sensing from stereo-pairs is diagrammed in Figure 1. Two projectors, $P1$ and $P2$, are shown with rays from a high-light point in the imagery converging on the model surface at P. If an aperture A is moved horizontally in a direction parallel to the flight-line (left to right) at a position H above the surface of the model, the ray from $P1$ through A will reach photomultiplier $PM1$ before the corresponding ray from $P2$ through A reaches photo-

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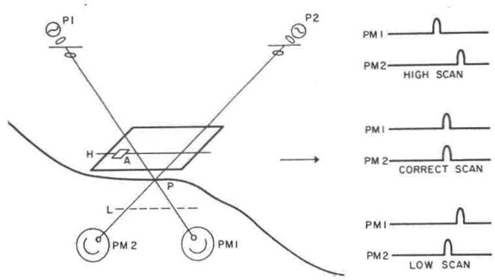

FIG. 1. Scanning of stereo model.

multiplier $PM2$. If the scanning is in the surface of the model, the rays will arrive at the photomultipliers at the same time, resulting in coincident electrical signals. If scanning is below the surface of the model, the signal will reach photomultiplier $PM2$ before it will reach photomultiplier $PM1$.

In the Automatic Stereomapping System, the mask and aperture take the form of a Nipkow disc, the original TV scanner. The disc is diagrammed in Figure 2; it consists of a circular disc with many small apertures arranged in a spiral. As the disc rotates, one aperture at a time moves across the window permitting the light—modulated according to the corresponding imagery in the diapositive—to pass through to the photomultipliers below. As the scanning progresses, the imagery in the entire window area is converted to a pair of electrical signals.

The primary sensing circuitry is diagrammed in Figure 3. It consists of a pair of short delay lines, a pair of signal correlators and a differencing network. The correlators multiply the two input signals on an instantaneous basis. The output of the differencing network is indicative of the magnitude and direction of the height error.

Suppose scanning is above the model so that the signal from photomultiplier $PM1$ is ahead of that from $PM2$. The delayed signal from $PM1$ will then be more nearly coincident with the signal from $PM2$, resulting in a large output from correlator 1. On the other hand,

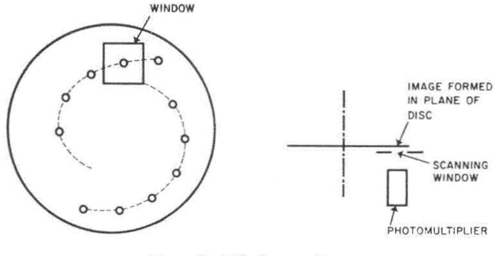

FIG. 2. Nipkow disc.

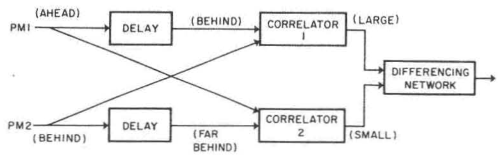

FIG. 3. Sensing circuitry (parenthetical notation for high scan).

the late signal, further delayed, will be far behind the leading signal so that the output from correlator 2 will be small. The difference network output will have a mganitude and sign corresponding to the large output from correlator 1 and a small output from correlator 2.

If scanning is at the proper height, the photomultipliers will produce signals that are coincident in time; the correlator outputs in this case will be equal, producing a zero difference output. If scanning is below the model surface, the situation shown in Figure 3 will be reversed, resulting in a signal of reversed polarity at the output. The signal from the differencing network is thus directly indicative of the height error and may be used to control a servo that locks the plane of the scanning to the model surface.

In the Stereomapper, the scanning disc tilts to conform roughly with the tilt of the terrain. This provides a more homogeneous signal for the correlators and improves the operation of the system.

Operation of the system is dependent upon the achievement of a satisfactory stereomodel. This is accomplished by an operator as in the usual Kelsh system, except that the operator is given a meter showing the degree of coincidence to help in the orientation process. Once a satisfactory model has been achieved, the system willl be started on the model and will make successive traverses, as shown in Figure 4, printing out altitude profiles in the form of a drop-line chart on photosensitive paper on an associated unit. An early example of a drop-line chart made by the machine is shown in Figure 5. At the same time, the terrain data picked up by photomultipliers is used to recreate the local

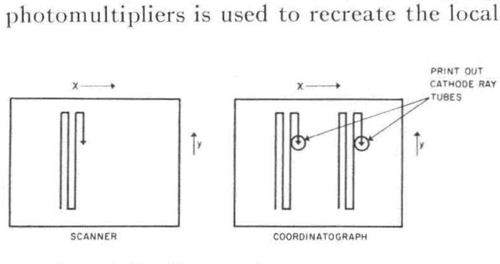

FIG. 4. Profiling mode on stereomapper.

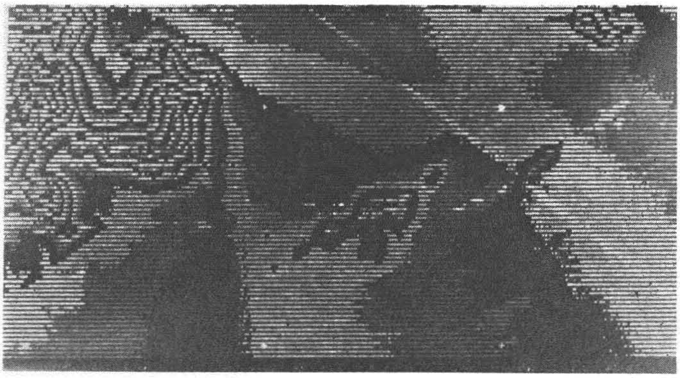

FIG. 5. Stereomapper altitude chart.

imagery on a TV-like cathode ray tube in the printout unit. This exposes a new photograph in which the imagery appears in its correct geographic position; the resulting print is therefore an orthographic projection photograph or orthophoto. Figure 6 shows an orthophoto corresponding to the drop-line of Figure 5. The two were made in about two hours.

The availability of the Hogan scanner early in the program permitted making an investigation to determine the most desirable scanning configuration. It was found that rugged terrain could be handled quite readily if a very small window were used to obtain a more homogeneous signal. The window size used in the present instrument is about $0.3'' \times 0.1''$. There is good reason to believe that this area is adequate to maintain a track under conditions that are marginal for manual operation.

Tests with the system to date show that it is capable of producing clean error signals to the servo for a one-tenth-millimeter height error even in areas that have very low contrast as, for example, in overexposed areas of the diapositives. There are, of course, limitations—the system cannot recognize that poor signals are being caused by a water area, that a cliff is so abrupt as to yield an x-parallax out of the range of the sensing circuitry, or that an image from one diapositive has no mate from the other because it was hidden from the view of the second camera. Since such occurrences are inevitable, facilities for manual intervention are provided.

The device has been delivered to the customer. The profiling unit is shown mounted in place on a Kelsh plotter in Figure 7, along with the associated electronics.

The Automatic Stereomapping System is conceptually a relatively simple device. Practically, however, it is limited in its application because of the optical problems associated with the direct projection system and the Nipkow disc. This limits the available signal

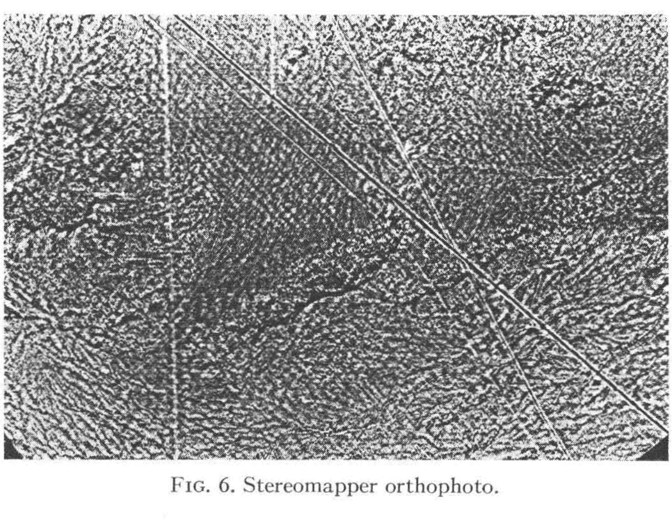

FIG. 6. Stereomapper orthophoto.

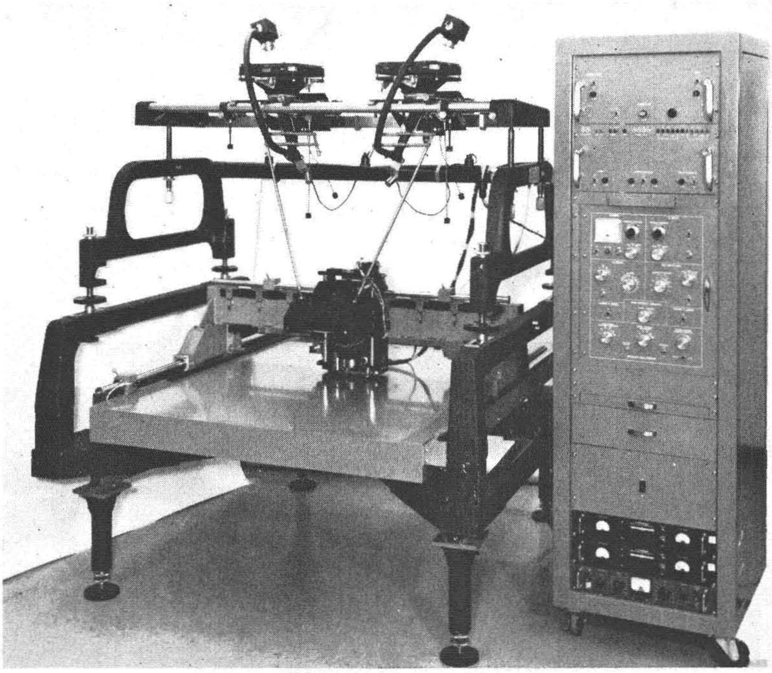

FIG. 7. Automatic stereomapping profiling elements.

in the corners of the model. In addition, in regions of high tilt, it is not practical to permit the scanning disc to conform to the surface because of the severe vignetting problem.

The Automatic Map Compilation System is designed to overcome the difficulties of a direct projection system. A small digital computer is used to determine the location of homologous points on the two diapositives. The areas surrounding these points are then scanned and correlation circuitry used to determine any error in the height estimate. It is therefore an analytical plotting machine that is provided with electronic height sensing to make the device completely automatic. As with the Automatic Stereomapper, the device will output both drop line altitude information and orthophotos. An early example of an orthophoto from this system is shown in Figure 8.

A photograph of the Map Compilation System is shown in Figure 9. This shows the two scanners for the diapositive readout at the upper level and two for the orthophoto and drop line print out at the lower level. An idea of the structure of the system can be obtained from the photograph—the design is very conservative so as to insure that there would be no question about the mechanical accuracy during the checkout phase.

A small digital computer is being used, operating at a point-loop cycle of 18 milliseconds at the present time. However, an excessive amount of this time is required for conversion between inconsistent computer and digital-to-analog converter formats. A goal of 10 milliseconds had been sought and seems quite reasonable for subsequent models. The remainder of the electronics involves the scanning circuitry with associated high-voltage supplies, the height sensing circuitry and the drives for the various carriages.

Neither of the systems described is considered to be the answer to completely auto-

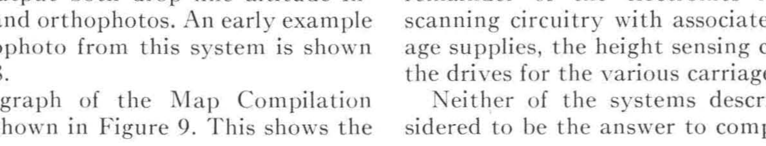

FIG. 8. Map compilation system orthophoto.

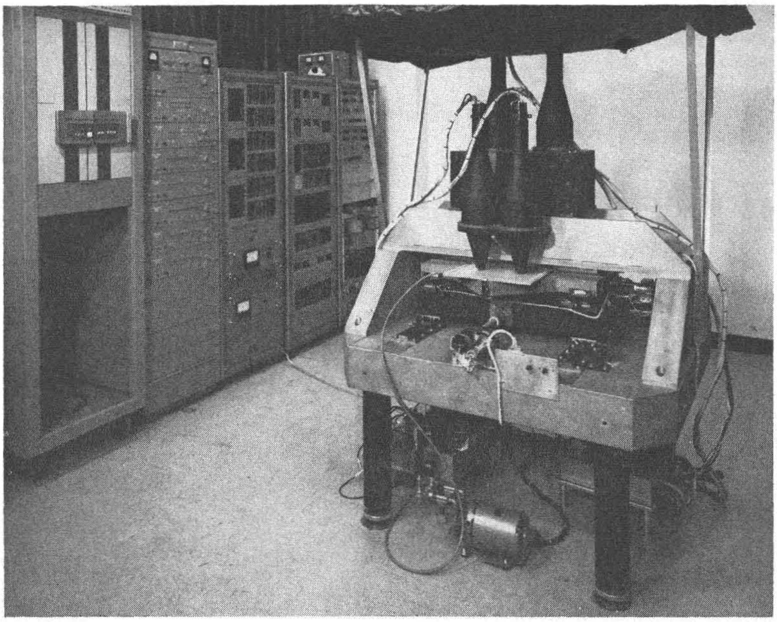

FIG. 9. Automatic map compilation system.

matic map compilation. Much remains to be done with respect to the logic required to bridge difficult terrain such as over water areas, steep cliffs, etc. The answer for now is the availability of a manual intervention facility. As experience is gained with the systems, it is hoped that the logic will improve so that less and less manual intervention will be required. It is believed that the height sensing circuitry will now handle anything a man can handle by direct stereoscopy, but a man does have the ability to interpolate height values into regions that are basically featureless. Several techniques have been suggested to handle these difficult areas and will be incorporated into the system as the work progresses.

ACKNOWLEDGMENT

The author wishes to acknowledge the contributions made to the programs described herein by Mr. M. O. Baker, project engineer for the Automatic Stereomapping System and Mr. G. Miller, senior mechanical engineer on the two projects.

*The AN/USQ-28 Mapping Survey Sub-System**

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BEFORE starting a detailed discussion of the AN/USQ-28 Mapping and Survey Sub-System, I will present some background material which may make possible a better understanding of the operational problems and how the new system will help overcome some of them.

The Air Photographic & Charting Service is the MATS subcommand responsible for meeting USAF requirements for photography

* Presented at the 28th Annual Meeting of the Society, The Shoreham Hotel, Washington, D.C., March 14–17, 1962.