FRONTISPIECE. The Stereotrigomat. (See Text, page 416.)

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The Stereotrigomat Universal Mapping System

Orthophoto . . . dropped-line contours . . . differential rectification . . . affine transformation . . . on-line computer . . . any photography . . .

(Abstract on next page)

INTRODUCTION*

BY 1950 APPROXIMATELY 90 per cent of the terrestrial surface of the earth had been mapped, but only about 2 per cent at such scales and with such an accuracy and completeness that the maps could be used for engineering projects. Now, in 1966, the situation has scarcely changed. The increase in information about our living space has been just sufficient to keep abreast of the great changes which continually take place on our planet, so that there is no real increase at all. Either surveyors keep obsolete map material up to date, or else new mapping in some areas leads to the neglect and obsolescence of existing surveys.

The technical revolution has given impetus to new developments in surveying. The modern mechanized and automated tools have certainly helped towards a very considerable increase of productivity. But a standstill would mean retrogression. The considerable

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* Read at the Annual Convention of the American Society of Photogrammetry, Washington, D. C., March 1966, by Mr. Wm. H. Cook under the title "Universal Mapping System 'Stereotrigomat.'"

The *Introduction, General Remarks* and *Development Trends* of the original paper are presented here in digested form. Additional background information is contained in the MANUAL OF PHOTOGRAMMETRY, Third Edition, 1966 (see page 384 in this issue).—*Editor* and continuous growth of the world's population, the necessary increase of food production, the urgent requirement of a higher standard of living (primarily in the young national states)—all these are problems from which new and even greater tasks will continually arise for the different technical disciplines.

Today the natural resources of our earth are being exploited with rather a modest degree of efficiency; on the other hand, efforts are constantly being made to improve the methods and techniques for the construction of industrial plants for utilizing the treasures of the earth or for generating more power. All this justifies one's firm belief that in the future our planet will continue to have room enough for everyone.

ABSTRACT: *The Stereotrigomat, developed and manufactured by Carl Zeiss/Jena, is a form of a first-order plotter with which can be produced orthophotos as well as conventional topographic maps. An additional convenience is the complete freedom from any dependence on the metric characteristics of the taking camera, such as super-wide angular field, and long and short focal lengths. The system includes a small electronic computer. Contouring is accomplished by connecting the ends of dropped-line profiles which are produced by manually scanning the model by narrow strips. Differential rectification is utilized to make the orthophoto. Mathematical affine transformations contribute to the flexibility of the device. Accuracy and rate-of-performance tests have been very gratifying.*

GENERAL REMARKS

It is probably unnecessary to outline the development of photogrammetry during the last 50 years. The planetable generally used in previous periods for topographic mapping has given way to stereoscopic plotting instruments including the Multiplex, Stereoplanigraph, and the Stereometrograph (Figure 1).

Several items in this development are noteworthy. Picture formats for mapping are normally either 18 by 18 cm. or 23 by 23 cm. The angular fields of view of aerial cameras range from 65° to 122°, focal lengths from 100 mm. (88—*Editor*) to 220 mm. Flight heights range from 300 to 8,000 m. above ground, and photograph scales from 1:2,000 to 1:220,000. As indicated by several writers in spite of rapid developments in information theory the aerial photographic print continues to be a most efficient manner for storing photographic information. One of the disappointing aspects of stereoscopic plotting is the time-consuming, wearisome human effort required, and the difficulty encountered in automating the process. One of the most efficient stereoplotting instruments is the Stereometrograph

FIG. 1. Stereometrograph Precision Plotting Instrument.

whose plotting rate is about 15 per cent greater than the Stereoplanigraph. The rate of the Stereometrograph has been shown to be 0.15 km.^{2} per hour where the map scale is 1:10,000.

TRENDS IN PLOTTING INSTRUMENTS

After World War II our colleagues in the Soviet Union wanted to extend the application of conventional plotting instruments to include super-wide-angle photographs. One method for accomplishing this was to change certain components on the plotter. However, the methods of Romanowski, Drobyshev, and Shukov utilized the idea of altering the angular field of the photograph—simply using short focal-length photographs on a plotter designed for long focal-length photographs—transforming the bundle of rays and affine plotting. G. Romanowski developed the Stereoprojector Romanowski SPR,* a system which is representative of the Soviet instrument designs. As in conventional instruments, the space coordinates x, y, z must be derived from the image coordinates $\bar{x}$ and $\bar{y}$ of the photograph $\mathcal{L}$ (Figure 2) which is inclined about a primary axis ϕ and a secondary axis ω relative to a horizontal plane $\mathcal{P}$. This task is also solved by this Soviet instrument and its numerous variations.

Expressed in terms of formulas, conventional instruments with their projection systems need to solve the equations,

$$x = \frac{(f \cos\omega - \bar{y} \sin\omega) \sin\phi + \bar{x} \cos\phi}{(f \cos\omega - \bar{y} \sin\omega) \cos\phi - \bar{x} \sin\phi} z \qquad (1)$$

$$y = \frac{\bar{y} \cos\omega + f \sin\omega}{(f \cos\omega - \bar{y} \sin\omega) \cos\phi - \bar{x} \sin\phi} z \qquad (2)$$

where f corresponds to both the focal length of the camera and the principal distance of the projector in the plotter. Hence it follows that, regardless of the small inclination components ϕ and ω (about 6^g each), the aperture angle of the camera must be

$$2 \tan \tau = 2^{3/2} s'/f$$

where

$$s \leq (\bar{x}^2 + \bar{y}^2)^{1/2}.$$

It is obvious that for very short focal lengths a conventional plotting machine cannot be economically constructed with acceptable dimensions.

In this case recourse is made of the affine technique where the following transformation is applied:

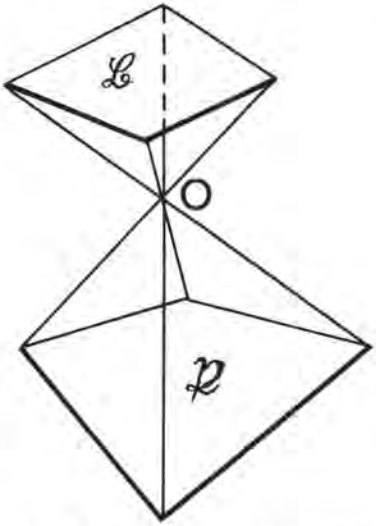

FIG. 2. Perspective transformation.

$$x = x^+$$
$$y = y^+$$
$$k.z = z^+,$$

i.e., compression or extension of the resulting space model in the z-direction depending on whether k is greater or smaller than 1. From this generally (i.e., $k \neq 1$) results the possibility of disregarding the congruent optical reconstruction of the path of rays in the plotter, and the desirable fact that the required aperture angle of the plotting instrument can be kept within manufacturing limitations by a free choice of the constant f required in projection (see Equations 1 and 2); the choice is now independent of the surveying camera used. In Equations 1 and 2 the tilt components ϕ and ω are the orientation angles that are determined in a simpler manner during the photogrammetric plotting process. In the Soviet designs these must be substituted for by a number of auxiliary quantities which, in the case of the SPR-2, are applied to the image coordinates in the following form:

$$\bar{x}^+ = \bar{x} + F_1(\phi, k, \bar{x}) + F_2(\phi, k, \bar{x}) + F_3(\phi, k, \bar{x})$$

$$\bar{y}^+ = \bar{y} + F_4(\omega, k, \bar{y}) + F_5(\omega, k, \bar{y}) + F_6(\omega, k, \bar{y}).$$

Colleagues in the Soviet Union, however, did not fully succeed in combining the two orientation quantities by suitable mechanisms with the intermediate auxiliary quantities in such a way that an empirical iteration method could be dispensed with. In the discussions on the super-wide-angle technique at the International Photogrammetric Congress in Lisbon 1964, experiences showed that these

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* MANUAL OF PHOTOGRAMMETRY, Third Edition, page 741. See page 384 in this issue.

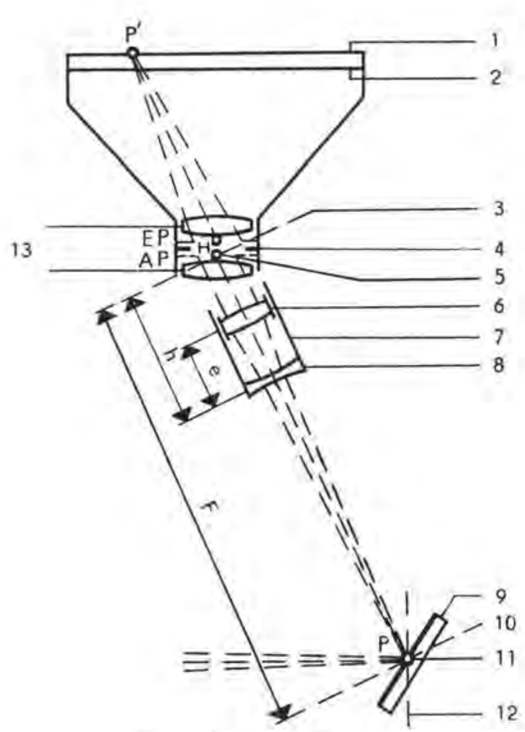

FIG. 3. Optical Projection.

costly orientation methods prevented desirable economic application.

The joint Canadian-American-Italian project of the Analytical Plotter† (AP-1, AP-2, AP/C) is primarily not concerned with the plotting of super-wide-angle photographs. It must be assumed instead that the designers of this system, which is based on purely digital techniques, were guided by considerations falling within the military scope of photogrammetric reconnaissance. The recently presented version AP/C appears rather to be a by-product of these activities. Such plotting machines with "mathematical projection" are not subject to any restrictions insofar as photographic parameters are concerned.

Although these two developments offered great freedom in choosing suitable photographic parameters, photogrammetrists in the last two decades have also considered a possible application of the expensive working techniques of conventional plotting and have investigated whether more efficient automatic systems could be introduced.

The experiments of Lacmann[2] and Ferber[3,4], who tried to apply a photographic technique to the position representation of a three-dimensional object, were obviously frustrated by the conservative way of thinking of mapping and surveying engineers in the 1930's in France and Germany. It was left to the photogrammetrists in the USA, and somewhat later also to those in the Soviet Union, to draw attention once again to such methods for increasing productivity in plotting.

The system of the Stereoplanigraph may well serve for illustrating a method which is known as differential, or slit, rectification. Figure 3 is a schematic representation of the design of a projection system. The plotting camera with the projection lens is brought into the spatial orientation that corresponds to a desired image location. At the projected point *P*, where a half-image of the stereoscopic measuring mark *P* is also present, a sharp image of point *P′* (and the nearby area) is produced. If point *P* follows the configuration of the ground in the virtual optical model, then the image scale at *P* (and the nearby area) changes in agreement with the effective flying height above ground. By differentially exposing a small photographic zone, a true-to-scale position of the imagery can thus be achieved.

A practical realization of such an idea is the Orthoprojector GZ 1* of the Optical Works, Oberkochen, which was designed as a special supplementary unit for use with the Stereoplanigraph. The floating mark is kept in contact with the surface of the terrain model and the exposure slit travels along its parallel set of strips in the y-direction transversely to the axis of flight at a uniform speed which depends upon the sensitivity of the photographic material and the slit width, the operator's task being merely to control the height of the measuring mark by means of a footwheel.

This type of differential rectifier, however, requires special projection systems in which the optical parameters correspond to those of the aerial camera used. Naturally such equipment cannot grant the desired freedom in the choice of the aerial camera which seems to be desirable both in economy and productivity.

If users of maps and plans were willing to abandon the symbolized map in favor of the orthophoto produced by differential rectification, then photogrammetry would be in a position of introducing further improvements

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† See pages 385 and 427 in this issue—*Editor.*

* M. Ahrend, et al, "The Gigas-Zeiss Orthoprojector, PHOTOGRAMMETRIC ENGINEERING, v. 31, n. 6, p. 1039, Nov. 1965; David Landen, Photomaps for Urban Planning," PHOTOGRAMMETRIC ENGINEERING, v. 32, n. 1, p. 145, January 1966.—*Editor*

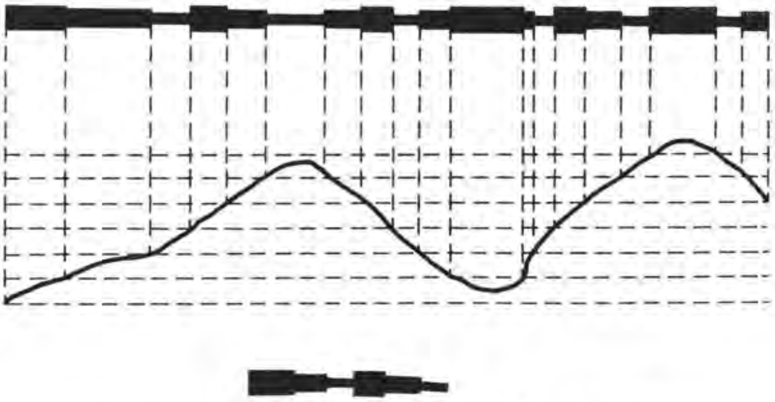

FIG. 4. Automatic height measurement in the profile strip.

in the working process by combining position plotting and relief plotting. Even then the result does not correspond to the conventional contour map.

During the last ten years American scientists designed the so-called "integrated mapping systems"‡ and, on the basis of their experimental work, made the first proposals for the temporary combination of position plotting and relief plotting. The tracing of the profiles for differential rectification suggested the idea of producing a signal usable for the graphical recording whenever a contour is intercepted by the measuring mark.

Figure 4 shows the profile of a strip of differential rectification. Simultaneously with the tracing, a signal is produced in the plotting machine when one of the pre-selected contours is intercepted by the measuring mark.

This method is illustrated by Figure 5 which shows a typical example of a figuration produced by adequately controlling the mapping device of the drawing table. The connection of the end points of the individual dropped-line sections results in the familiar contour line representation of topographic maps.

Orthophotoscopy and dropped-line representation as the adequate techniques of photogrammetry can to a high degree meet the time requirements of modern land surveying. Experimental results already available indicate that one may expect an *increase* in performance by a *factor of ten*. The instrumentation required for such an operational technique can already be manufactured with a moderate increase in components and cost.

Modern advanced concepts of automation of photogrammetry should not be completely

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‡ John Boyajean, "The Implementation of the Integrated Mapping System," PHOTOGRAMMETRIC ENGINEERING, v. 27, n. 1, p. 55, March 1961.

FIG. 5. Section of a dropped-line contour chart.

ignored; it seems doubtful, however, whether these concepts can make equally large contributions to solving the tasks, and whether and when they can be produced at a reasonable cost. We cannot within the scope of this paper discuss the design of Hobrough's Stereomat principle which electronically simulates the stereoscopic measurement performed by an operator. The impression prevails, however, that the equipment outlay is still rather expensive. But in conjunction with orthophotoscopy and dropped-line contour plotting, an almost fully automatic plotting system is obtained; on the other hand, we do not attach great importance to experiments now being made in the USA where photogrammetrists try to trace contours directly because such a technique necessarily involves the unproductive plotting of position and relief in separate operations.

THE STEREOTRIGOMAT SYSTEM

The aim pursued in designing the Stereotrigomat System was to incorporate into one stereomapping instrument three additional features (which had been considered essential and which were mechanically feasible) to increase the scope of application of the equipment. These functional extensions are:

a. The affine technique enabling *all* systems of vertical photography to be utilized without any limitation.
b. Differential rectification in order to replace the plotting of positions connected with time-consuming interpretation by conventional photographic orthophotoscopy.
c. The plotting of dropped lines in the strip of differential rectification in order to combine the plotting of both position and relief into one operation.

In the foregoing exposition of photogrammetrical methods were already discussed the state of development of the theory of transformed bundles of rays and of the affine technique attained in the Soviet Union. The fundamental advantages of this plotting technique have in recent years also inspired designers in other countries to deal with the possibility of an *exact* application of these theories. So far, however, only *approximate* solutions were achieved to enable the unknowns of orientation to be determined after several time-consuming iteration steps. Pursuing the theory of affine plotting, Zeiss laboratories in Jena succeeded in finding an exact solution which could also be fabricated from the design point of view in such a way that the iteration technique was no longer required for the orientation process.

The Stereotrigomat (Frontispiece) is, in principle, an analogue computer solving the problem of the central projective by means of mechanical rods. In this respect the Stereotrigomat is comparable to the well-known stereoautograph in that the three-dimensional central perspectives are simulated by a straightedge system in two planes. The basic linkage used in a conventional way controls the movement of the measuring mark in the space model. Thus the mode of operation of the Stereotrigomat may be compared with those instruments using mechanical projection (it is thus distinguished from pure computer systems, such as AP/C and Supragraph).

Guided by these ideas, Zeiss of Jena developed the Stereotrigomat which was on display for the first time at the Leipzig Spring Fair, 1965. Since January 1965 two trial models of the instrument have been subjected to tests. As the results so far obtained come up to the required standard with regard to geometrical accuracy, photographic quality of differential rectification, and the representation of the dropped lines, series production of the instrument has already begun.

The Stereotrigomat comprises an instrument system in which the basic equipment consists of a universal first-order stereoplotter and a device for differential rectification. Optional extras for use with the basic device system include: a profile control device for the production of dropped lines; a profile memory device for simplifying and accelerating differential rectification and producing dropped lines; a recorder; a second drawing table, etc. The main components of the device system are: the stereocomparator including the optical observing system, the horizontal arrangement of the photograph, and the tilting facility; the four so-called rectification computers for reducing the measured image coordinates to vertical photographs; the so-called model computer for the projection of the reduced image coordinates to model coordinates.

Assuming that the ϕ-axis is primary and the ω-axis secondary (Figure 6), one obtains Equation 3 for the reduced image coordinate y'' and Equation 4 for the reduced focal length c_k' that corresponds to the respective image point:

$$y'' = y' \cos \omega + c \sin_k \omega \qquad (3)$$

$$c_k' = c_k \cos \omega - y' \sin \omega. \qquad (4)$$

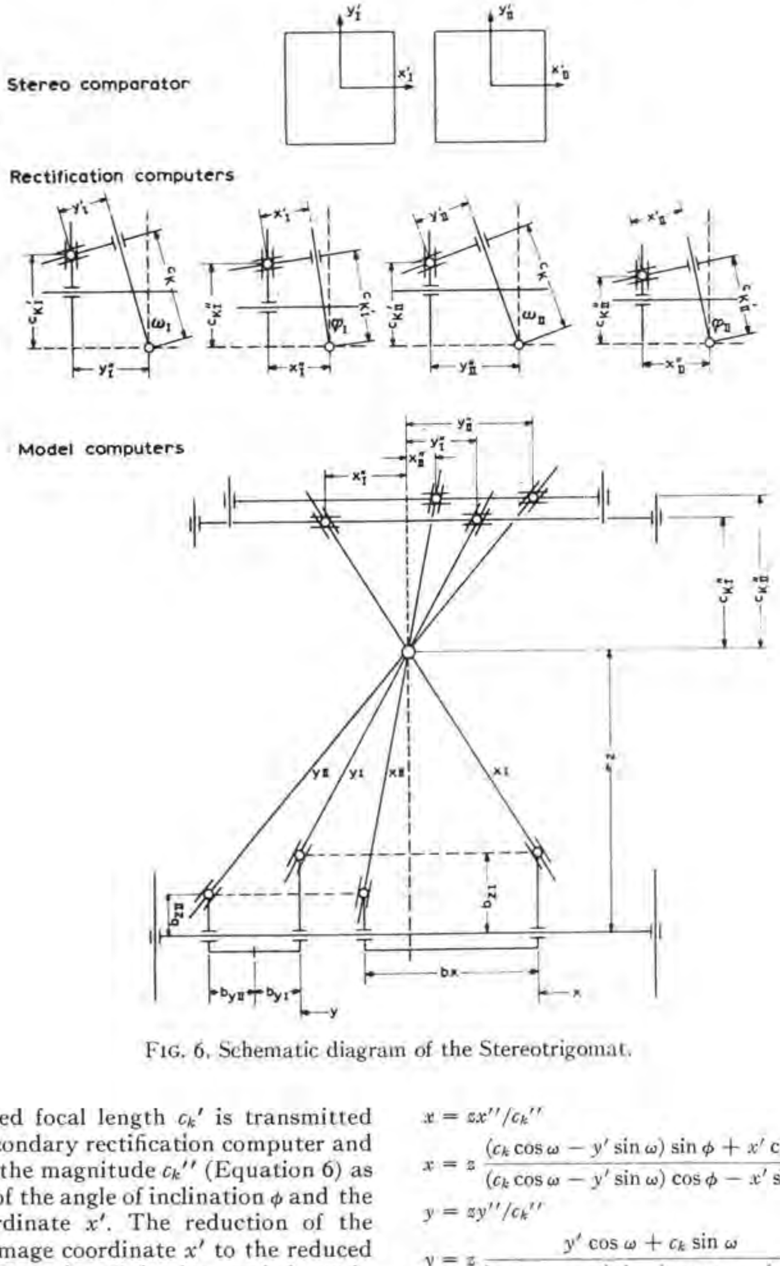

FIG. 6. Schematic diagram of the Stereotrigomat.

This reduced focal length c_k' is transmitted into the secondary rectification computer and reduced to the magnitude c_k'' (Equation 6) as a function of the angle of inclination ϕ and the image coordinate x'. The reduction of the measured image coordinate x' to the reduced value x'' (Equation 5) is also carried out in this computer:

$$x'' = x' \cos\phi + c_k' \sin\phi$$

$$x'' = x' \cos\phi + (c_k \cos\omega - y' \sin\omega) \sin\phi \tag{5}$$

$$c_k'' = c_k' \cos\phi - x' \sin\phi$$

$$c_k'' = (c_k \cos\omega - y' \sin\omega) \cos\phi - x' \sin\phi. \tag{6}$$

For each of the two photographs the values x'', y'', c_k'' have to be transmitted into the model computer, in which the model coordinates x, y, z are determined;

$$x = zx''/c_k''$$

$$x = z \frac{(c_k \cos\omega - y' \sin\omega) \sin\phi + x' \cos\phi}{(c_k \cos\omega - y' \sin\omega) \cos\phi - x' \sin\phi} \tag{7}$$

$$y = zy''/c_k''$$

$$y = z \frac{y' \cos\omega + c_k \sin\omega}{(c_k \cos\omega - y' \sin\omega) \cos\phi - x' \sin\phi} \tag{8}$$

$$z = bc_k''/(x_{\text{II}}'' - x_{\text{I}}).^* \tag{9}$$

The plotting of super-wide-angle photographs is done in the Stereotrigomat through an affine transformation of the bundle of rays. In this case the focal lengths c_k'' (reduced in the rectification computers and multiplied by an affine factor $k=1$; 1.5; 2; 3; 4) are trans-

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* This equation is true only for $b_z=\phi_1=\phi_2=0$ and $\omega_1=\omega_2$.

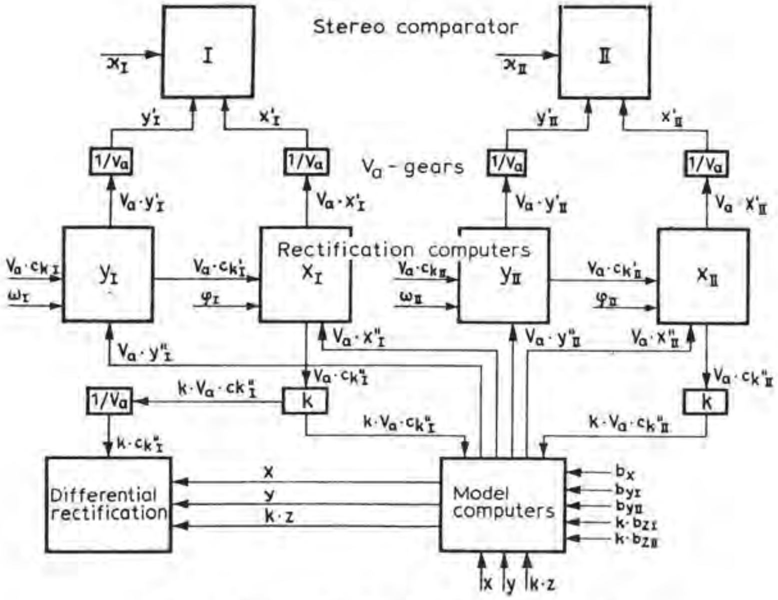

FIG. 7. Information flow in the Stereotrigomat.

mitted into the model computer. This technique is mathematically exact and does not require any decentering nor any additional tilt of the photograph, or other departures from the usual working process. The affine factor is defined as follows, where for aerial photogrammetric plotting,

$$k = M_{m(z)}/M_{m(x,y)} = m_{m(x,y)}/m_{m(z)}, \tag{10}$$

and for plotting terrestrial photographs,

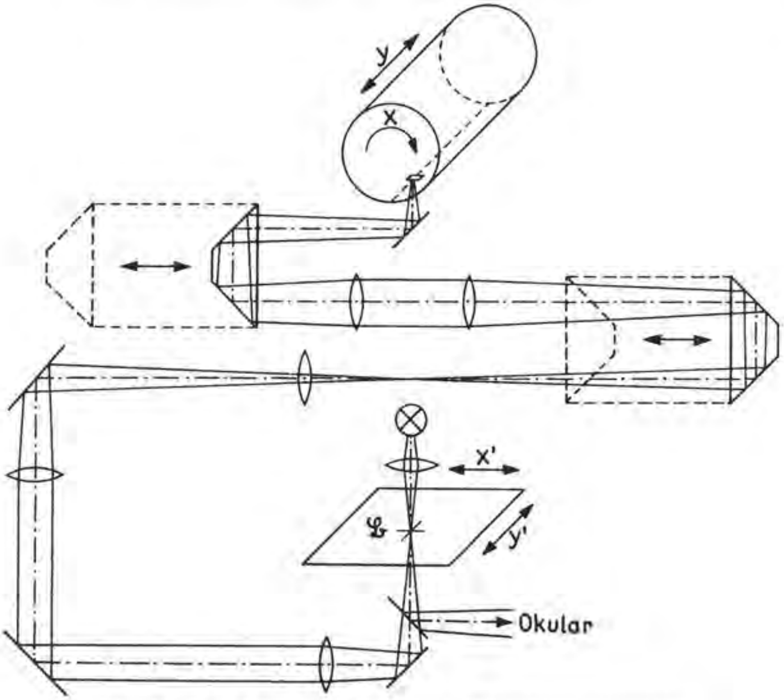

FIG. 8. Path of rays of differential rectification equipment.

$$k = M_{m(y)}/M_{m(x,z)} = m_{m(x,z)}/M_{m(y)} \qquad (11)$$

in which k is the affine factor, M_m is the scale of model, M_m is the ratio $1:m_m$, and m_m is the scale number of the model.

An additional feature of particular interest in the Stereotrigomat is a device for enlarging or reducing the image coordinates and focal lengths by the factor v_a. By means of these v_a gears it is possible to carry out the rectification at an enlarged scale ($v_a = 1.6$) in the range of the short focal lengths ($c_k = 35$ to 215 mm.). With long focal lengths ($c_k = 215$ to 600 mm.) a reduced scale is employed ($v_a = 0.5$ or 0.625, respectively). Thus, in the first case a gain in accuracy is achieved in which critical, short focal lengths are enlarged. In the second case, which is expected to apply less frequently, a decrease in accuracy is likely to occur, but on the other hand the instrument's dimensions are kept within reasonable limits.

In Equations 3 to 9 the information flow is assumed to take place from the photograph to the model so as to have a clear-cut situation. For kinematic reasons the opposite way was chosen in the practical design (Figure 7). The model ranges are so large that both air photographs and terrestrial photographs can be plotted ($x = y = \pm 350$ mm.; $z = 200$ to 600 mm.; $b = \pm 280$ mm.).

The differential rectification equipment is housed in the left-hand upper structure of the measuring instrument (Frontispiece). For rectification, use is made of the left photograph of the stereoscopic pair. The path of rays is schematically shown in Figure 8, the flow of information in Figure 7. The photographic material (film or paper with a maximum format of 600 by 750 mm.) is stretched on a cylinder; the scan width (x-direction) can be varied between 0.5 and 16 mm. and the magnification ratio of image scale to rectification scale between 0.7 and 5 times.

The most needed component of the differential rectification equipment is the inversor for controlling the displacement prisms (Figure 9). This inversor must fulfill two requirements: *sharp focus* between photograph and rectified copy according to Equations 12, 13, 14; image formation at the desired *scale* as a function of magnification between photograph and model v_m and as a function of magnification between rectification and model $v_{e/m}$ (Equations 15 and 16).

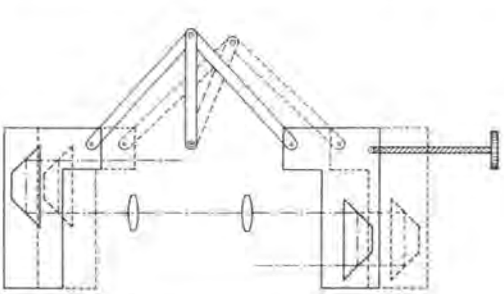

FIG. 9. Inversor for controlling the displacement prisms.

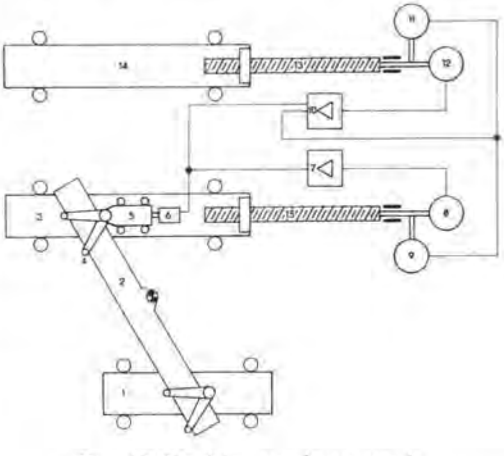

FIG. 10. Precision synchro control.

For the optical sharp focus, Equation 12 must be obeyed:

$$1/a + 1/a' = 1/f_e \qquad (12)$$

where a is the distance of the image plane from the front principal point of the projection lens, a' is the distance of the projection plane from the rear principal point of the projection lens, and f_e is the focal length of the projection lens ($f_e = 250$ mm.; 1:25).

The distances a and a' can be obtained from Equations 13 and 14:

$$a = f_e(1 + 1/v_e) \qquad (13)$$

$$a' = f_e(1 + v_e) \qquad (14)$$

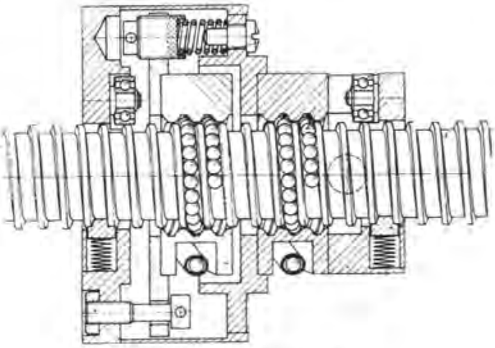

FIG. 11. Ball spindle.

FIG. 12. Orthophotograph 1:10,000 (before reduction), produced from wide-angle air photographs 1:30,000. (The illustration is a reduction of 0.45.) By courtesy of Rikets Allmana Kartverk, Stockholm.

where v_e is the magnification ratio between rectification and air photograph. In the Stereotrigomat v_e is

$$v_e = v_m \cdot v_{e/m} = a'/a \tag{15}$$

in which

$$v_m = z/c_k'' \tag{16}$$

where v_m is the magnification between model and air photograph, $v_{e/m}$ is the magnification between rectification and model. Equations 13 and 14 can therefore be transformed into Equations 17 and 18:

$$a = f_e + \frac{f_e \cdot c_k''}{z \cdot v_{e/m}} = f_e + m \tag{17}$$

$$a' = f_e + \frac{f_e \cdot z \cdot v_{e/m}}{c_k''} = f_e + m'. \tag{18}$$

The values m and m' are determined by means of an electrical computing bridge, and $v_{e/m}$ is represented by a gear change.

The advantages of this differential rectification equipment lie in the fact that all control elements required can be transmitted directly from the rectification computers and the model computer (x, y, z, c_k''), that no additional image orientations are necessary, and that in the imaging optics only a narrow angular field is used.

Another point of importance for this solution is the fact that the plane of critical focus of the image of the diaphragmed field of view coincides exactly with that plane, in which the projection is retained on the photographic emulsion carrier (in contrast with the Gigas-Zeiss Orthoprojector). As a result one obtains high image quality even if extreme super-wide-angle photographs are used for differential rectification. As it is not necessary to restore the inner orientation, no exchange of projectors need be made for using photographs of other types of cameras. This mode of differential rectification with frontal image projection is comparable to the TV systems used in the USA, but avoids inferior image resolution; however, it does not allow the production of color differential rectifications.

The combination of position representation made possible by orthophotoscopy and relief plotting is made possible in the Stereotrigomat with the help of a device known as *Orograph* (a relief represented by means of *dropped lines* is therefore termed *orogram*). The principle is shown in Figure 4.

In order to reach a solution which is also suitable for direct scribing, a fine point was used in the orograph for scribing the dropped lines. For reasons of accuracy it was necessary

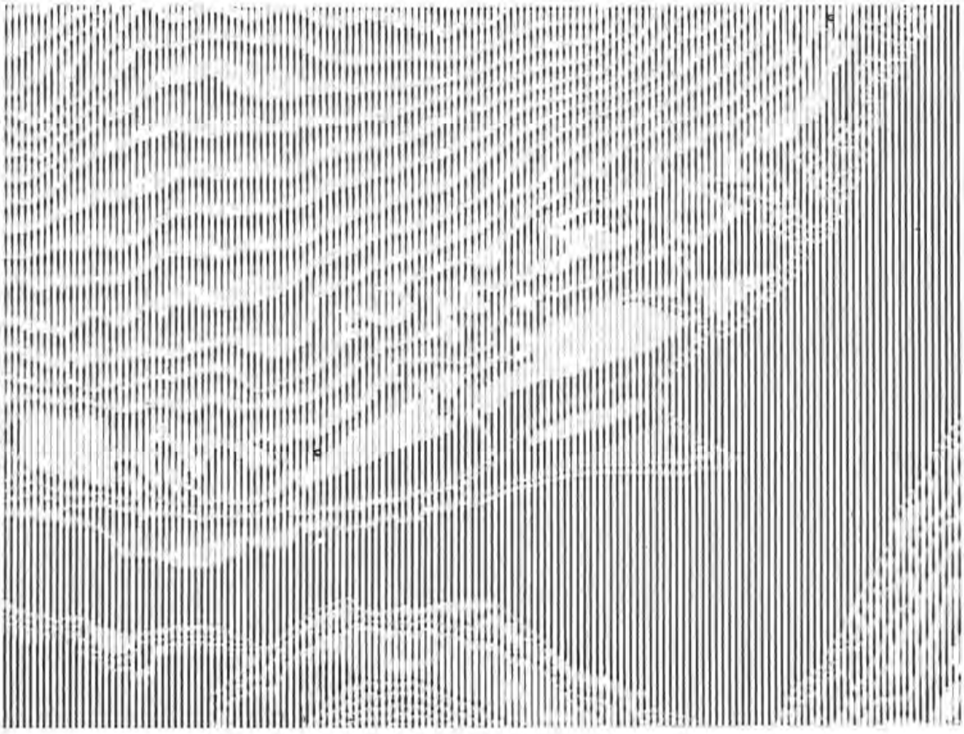

FIG. 13. Orogram for orthophotograph Figure 12.

to dispense with raising and lowering the tool. The contour is produced without interruption of the traverse line, suitable means being used to ensure that merely the thickness of the line is changed after each height interval. Also the direction of the change in height is marked by the sequence of the line thicknesses.

The plotting instrument is electrically coupled to the Orograph to transmit the height information. By means of an optical-electrical transducer, the height values are measured and digitized in the input of the Orograph. For further processing the data obtained are fed into a reversible counter of variable capacity. A sampling unit continually controls the result of count and delivers coincident pulses when predetermined contour lines are intercepted. These pulses are transmitted to a control circuit where they are converted into the cyclical signal sequence required for dropped-line plotting in accordance with the instantaneous change in height and depending on the direction of the change after the preceding contour. The special head of the Orograph allows it to be used in place of the standard drawing head. There are altogether 35 different adapters available which permit all common contour intervals to be set at scales of 1:1,000 to 1:100,000.

Particular design features of the Stereotrigomat are the precision synchro control (Figure 10) and the ball spindle (Figure 11). The synchro control enables the electrical transfer of displacements of a carriage to one or several other carriages. Displacement of carriage 1 causes a turning movement of arm 2, and a displacement of the auxiliary carriage 5 relative to carriage 3 and the zero indicator 6. In this indicator is produced a voltage which, amplified in the amplifiers 7 and 10, drives the spindles 13 and 15 through motors 8 and 12. The carriages 3 and 14 are moved until the auxiliary carriage 5 and the zero indicator 6 are again in their zero positions. The selsyns 9 and 11 serve to synchronize the two spindle rotations.

This precision synchro control was so designed that it will meet the requirements both in static accuracy (zero position setting of the auxiliary carriage 5 to about 1 μ) and in dynamic accuracy (at movements of 20 mm./sec in the model). In the Stereotrigomat twelve synchro controls as in Figure 10 have been incorporated. The corresponding 24 amplifiers are accommodated in the amplifier

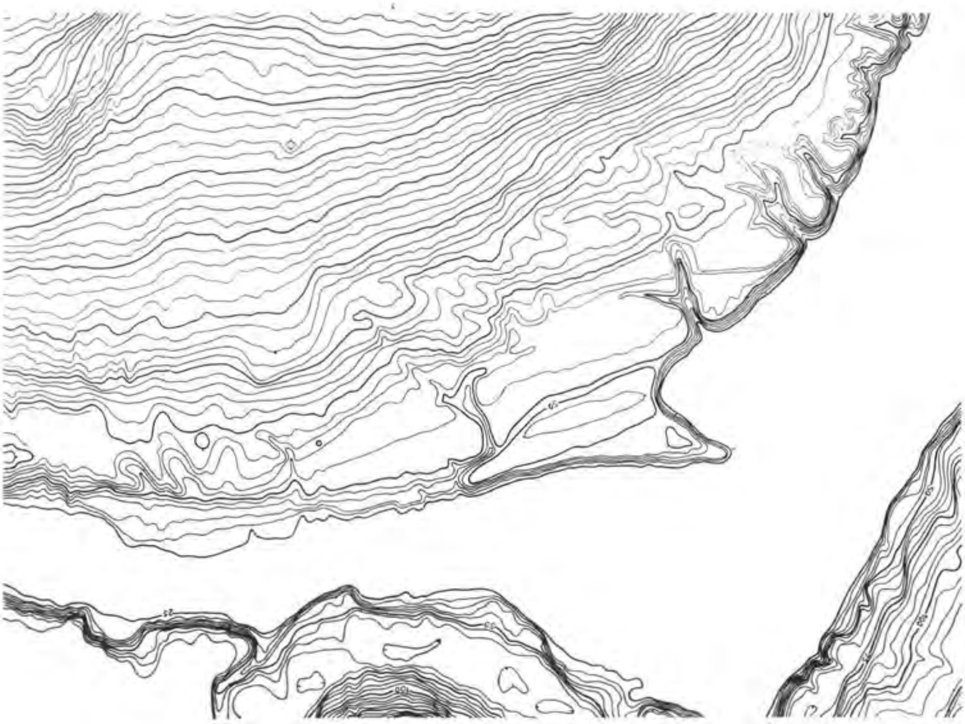

FIG. 14. Contour line plan derived from Figure 13.

cubicle (shown at the left in the Frontispiece).

A second design feature of the Stereotrigomat is the ball spindle as measuring device (Figure 11) which, compared to usual spindles, is distinguished by three advantages: low torque, practically no backlash between spindle and nut, and practically no wear. Contact between ball spindle and nut is made via ball bearings so that there is no sliding—only rolling friction. Two such nuts are

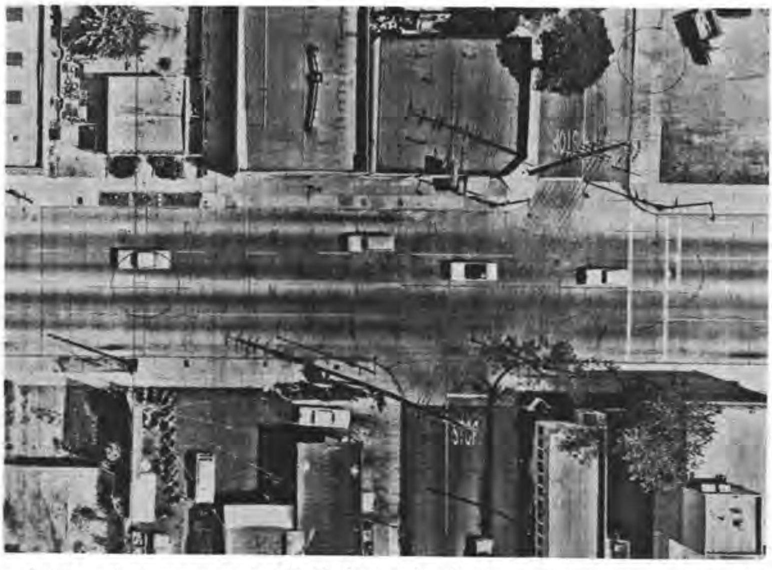

FIG. 15. Orthophotoscopic town map 1:180 (before reduction), produced from wide-angle aerial photographs 1:620. (The illustration is a reduction of 0.25.) By courtesy of the City of Los Angeles.

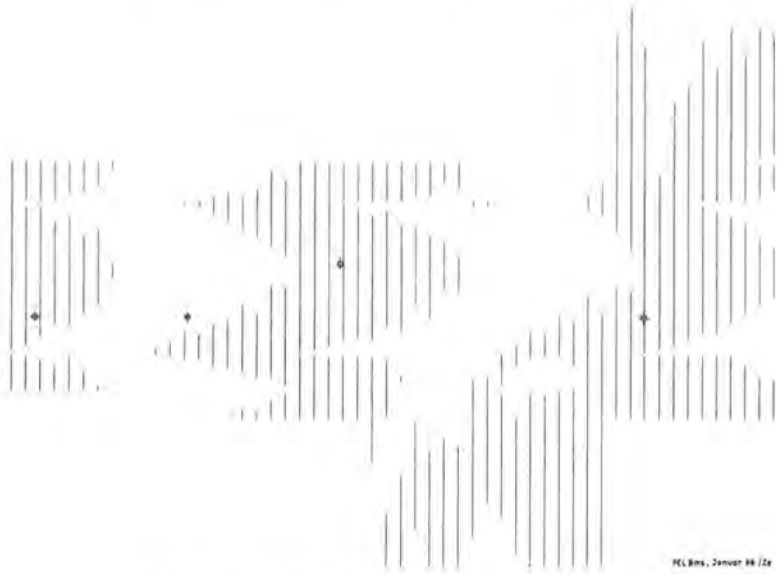

FIG. 16. Orogram for orthophotograph Figure 15.

drawn together by spiral springs so that backlash is avoided.

APPLICATIONS OF THE STEREOTRIGOMAT

A main field of application of the Stereotrigomat is the stereoplotting and the point-by-point measurement of stereomodels, where maximum accuracy is required for the differential rectification and the production of dropped lines. Due to the relatively large model ranges ($x=y=\pm 350$ mm., $z=200$ to 600 mm.), a favorable magnification ratio between image and model scale is generally possible. It is well known from the investigations carried out with the Stereoplanigraph in Jeana that the plotting accuracy is greatest when the model scale is 2 to 3 times that of the image scale. The maximally applicable

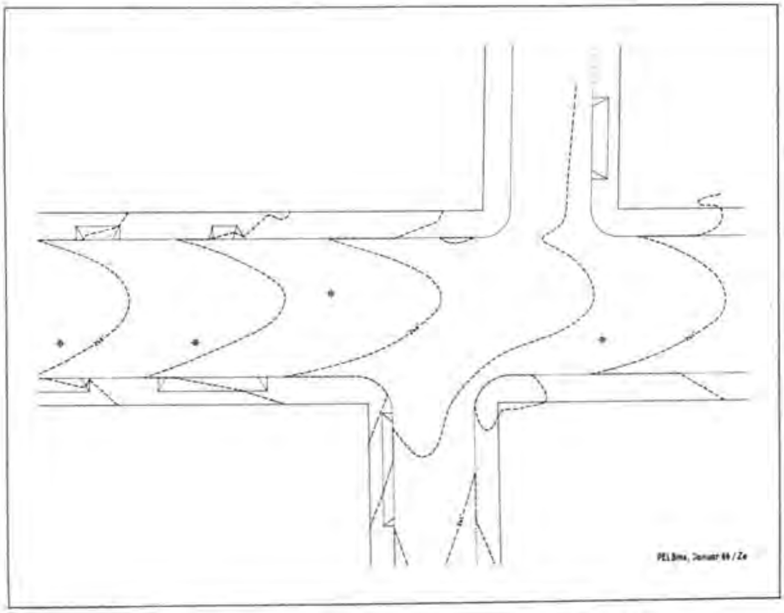

FIG. 17. Contour line plan derived from Figure 16.

FIG. 18. Orthophotograph 1:31,680 (before reduction), produced from super-wide-angle air photographs 1:74,400. By courtesy of Dept. of National Mapping, Canberra.

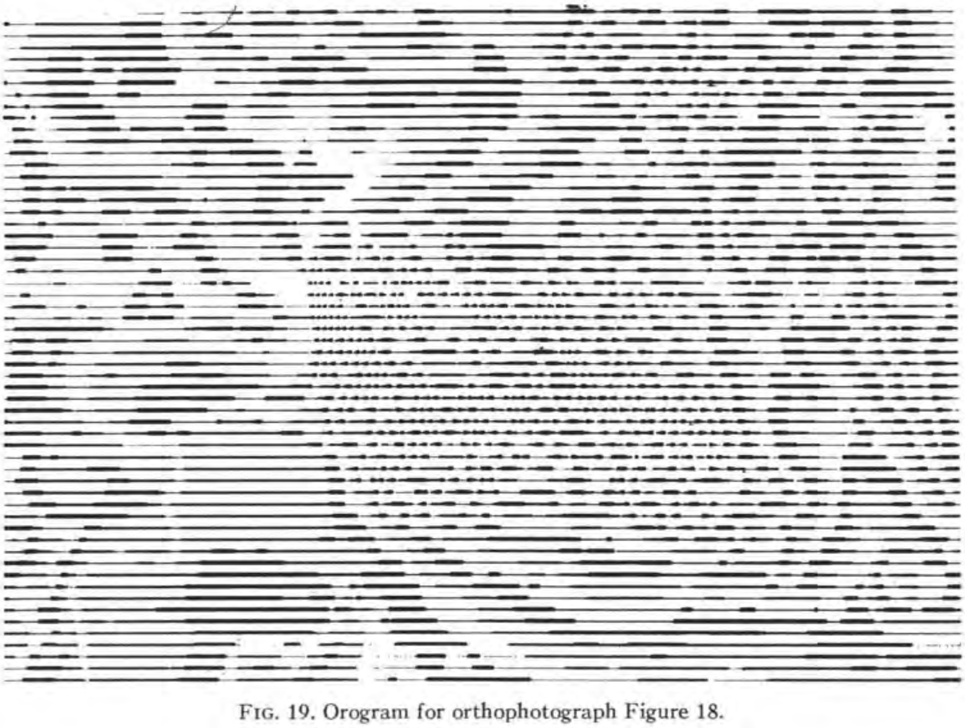

FIG. 19. Orogram for orthophotograph Figure 18.

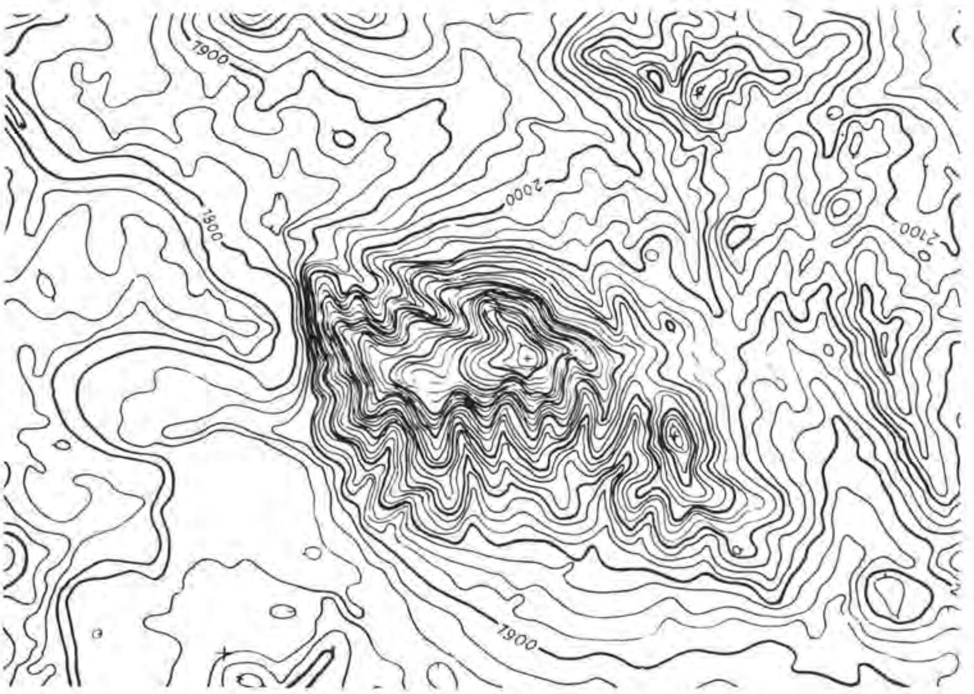

FIG. 20. Contour line plan, derived from Figure 19.

magnifications from the image to the model scale are given in Table 1.

The transmission from the model scale to the map scale is effected by interchangeable gears, the maximum magnification being 5 times. The drawing table (900 mm. by 1,200 mm.) is arranged above the measuring instrument on the right-hand side of the eyepiece, so that the instrument is suitable for operation by a single person (height of the tracing area above the floor is 95 cm.). (See the Frontispiece.)

Numerical plotting facilities are provided for the connection of recorders. The model coordinates x, y, z and the base components b_{yI} and b_{yII} can be directly transmitted from plugs to the recorder. The recording facility for the base components b_y has been provided, because for numerical plotting or for relative orientation by means of computational techniques, it may sometimes be useful to record the residual y-parallaxes. Recorders, which may be directly connected, are the Coordimeter Mod. A-C (with invoicing ma-

TABLE 1. MAXIMUM MODEL MAGNIFICATIONS

c_k		m_b/m_m
36	(1818)	3.5
55	(1818)	3.5
70	(1818)	3.5
115	(1818)	3
210	(1818)	2.5
350	(1818)	1.5
500	(1818)	1
88	(2323)	2
150	(2323)	2.5
210	(2323)	2.5
300	(2323)	1.5
600	(2323)	0.8

TABLE 2. DATA FROM TEST I, 6-INCH CAMERA, 1:30,000 PHOTO SCALE. SEE FIGURES 12, 13, AND 14

Wide-angle camera, $f = 15$ cm.
Image format—23 cm.×23 cm.
Image scale—1:30,000
Map scale—1:10,000
Slit width (position)—4 mm.
Strip width (relief)—2 mm.
Time required for relative and absolute orientation (1 model)—2 hours
Time required for position representation:
- (a) for the shole model—3.5 hours
- (b) for the section shown in Figure 20—1.5 hours

Time required for relief representation:
- (a) for the whole model—7.0 hours
- (b) for the section shown in Figures 13 and 14—3.0 hours

TABLE 3. DATA FROM TEST II, 6-INCH CAMERA, PHOTO SCALE 50 FEET PER INCH. SEE FIGURES 15, 16, AND 17

Wide-angle camera, $f=15$ cm.
Image format—23 cm.×23 cm.
Image scale—1:620
Slit width—8 mm.
The measuring mark is moved only within the range of the street up to the borders of propriety on either side.
Map scale—1:180
Time required for relative and absolute orientation—1.5 hours
Time required for position and relieve (1 model)—1.25 hours

TABLE 4. DATA FROM TEST III, SUPER-WIDE-ANGLE CAMERA, 1:74,400 PHOTO SCALE. SEE FIGURES 18, 19, AND 20

Super-wide-angle camera, $f=88$ mm.
Image format—23 cm.×23 cm.
Image scale—1:74,400
Map scale—1:31,680
Slit width—2 mm.
Time required for relative and absolute orientation (1 model)—2 hours
Time required for position and relief (1 model)—6.5 hours
Time required for the Section shown in Figures 18, 19, and 20—2.0 hours

chine as a small computer) or the Coordimeter Mod. D for pure recording purposes (without computer).

The Stereotrigomat incorporates all facilities that are necessary for instrumental aerial triangulation. These include *base-in* and *base-out* (±280 mm.), the base components b_{yI}, b_{yII}, b_{zI}, b_{zII}, and the optical switch. Although analytical aerial triangulation is already widely used today, the instrumental aerial triangulation will, nevertheless, also be used to advantage in the future primarily for shorter triangulation strips. Due to the high accuracy of the instrument in general and of the orientation elements in particular, the stereotrigomat is also suitable for aerial triangulation with independent pairs and for aerial triangulation with auxiliary data (statoscope, horizontal camera, etc.).

For plotting terrestrial photographs, which must approximately correspond to the parallel or convergent modes (maximum convergence ±11°), the necessary change-over facility for the drive elements y–z and the altitude counter has been provided. The camera axes may be inclined relative to the horizon by ±5.5°. In the orthophotograph-orogram combination, three typical tests have so far been completed on prototypes of the stereotrigomat; test data are shown in Tables 2, 3, and 4 and illustrated by Figures 12 to 20.

SUMMARY

The stereotrigomat system is a universal plotting instrument which allows the unrestricted application of surveying cameras of extremely long focal lengths and of super-wide angles. By simultaneously plotting the position by means of orthophotoscopy, and the relief by means of orography, the performance of photogrammetric plotting is expected to be considerably improved as compared to the use of conventional systems.