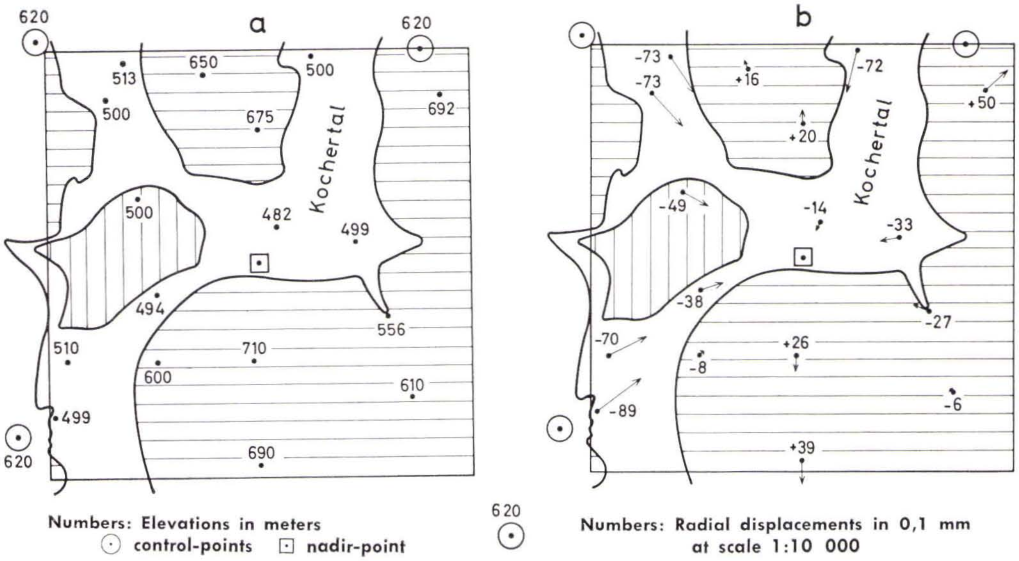

FIG. 1. Theoretical example of residual errors in aerial mosaics. The example is based on an assumed photograph (flying height 3,000 m) taken with a camera of 6-inch focal length and 9 by 9-inch format, rectified with reference to the four marginal "control points" having equal elevation.

DR.-ING. M. AHREND*
DR.-ING. W. BRUCKLACHER
DR.-ING. H. K. MEIER
H. UTZ
Carl Zeiss
Oberkochen, West Germany

The Gigas-Zeiss Orthoprojector

Orthophotographs free from relief and tilt displacements can be produced with this device for use particularly in constructing mosaics for urban planning.

(Abstract on next page)

INTRODUCTION

ANY SINGLE AERIAL photograph, due to its perspective projection, will represent the true map position of ground points *only* if the surface of the terrain is an ideal plane. In this ideal case, the enlarged or rectified (for camera tilt) prints of aerial photographs would be exactly equivalent to a conventional map, with the exception of residual errors which are, however, insignificant in this particular case.

In all those cases in which the terrain has relief, the enlarged or rectified print of the aerial photograph exhibits certain radial "deviations" from the true map position toward or away from the nadir point.

In stereophotogrammetry, these displacements give rise to so-called x-parallax. The mechanical or numerical elimination of x-parallax in stereophotogrammetry leads to

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"error-free" maps. In single-image photogrammetry, these parallax deviations are responsible for residual errors in the so-called "aerial mosaics," the magnitude of which is illustrated by an example (Figure 1). (This example does not necessarily imply that it would be appropriate to perform a rectification in this terrain and with the control points available.)

For many purposes the accuracy of aerial mosaics (possible through the use of longer focal lengths or by partial rectification) is entirely sufficient. One of these is the large field of general planning and development. The world-wide utilization of so-called photogrammetric rectifiers (among which the German-made SEG V occupies a special position in many respects) amply proves that the aerial mosaic constitutes an economical technique and is adequately sufficient for many requirements. The advantages of the aerial mosaic are apparently more important in this application than the drawback of small departures from the true map position. For these uses, the possibility of producing a rectified print within a few minutes is obviously more interesting than the advantage of precise stereophotogrammetric mapping of the same area, which may require a few days' work.

Thus two practical photogrammetric techniques and their end products are available: (1) the aerial mosaic; and (2) stereoplotting. It is only logical that attempts should be made to develop a third method which would combine the advantages of both the conventional techniques: (3) a photomap, which should combine the wealth of details contained in the aerial photo with the planimetric accuracy of the map.

The techniques for the production of a photomap are based on the process of transforming the perspective projection of the aerial photograph into a corresponding orthogonal or parallel projection. For practical reasons, this transformation is made by "rectification by strips," for which the ground elevation of each point along the resultant "profiles" must be known. These ground elevations should best be determined in a stereophotogrammetric plotter. The accuracy of a transformation derived in this manner *increases* as the width of the strips is *reduced*.

Before discussing related research work and the development of the GZ 1 Orthoprojector, a few remarks are made relative to the status of technology, and particularly on the production of photomaps (or "orthophotograms") as a valuable new technique for the methods of rectification and stereoplotting.

ABSTRACT: *The ZEISS GZ 1 Orthoprojector is designed for the production of "photomaps" by strip-by-strip transformation of photographs from perspective to orthographic projection. The following characteristics are of particular interest: Direct optical projection with magnifications ranging up to 4×, rigorously sharp imagery at central slit point, suitability for black-and-white and color photography, interpolation device for reduction of mismatches resulting from residual errors of measurement.*

PRIOR SOLUTIONS

Aside from Scheimpflug's "Zonal Transformer," the idea of building instruments for preparing such orthophotograms was probably conceived first by *Lacmann*.[1] *Ferber's* publication[2] from the same period is another example of the duplication so often found in technology in the conception of ideas for which the ground is prepared.

The prototype instruments built according to *Ferber's* and *Lacmann's* suggestions apparently did not come up to general expectations. This may be one of the reasons why it was not until 25 years later that these ideas were taken up again or even re-invented independently (*Beam*, Orthophotoscope, 1955.[3]) Work on this project has progressed ever since. Additional research was undertaken primarily in the United States and the USSR (where the instrument is called "slit rectifier").

Table 1 summarizes these developments, as far as they have come to the knowledge of the authors. The references at the end of the paper have intentionally been limited to such publications which report on instruments actually manufactured.

The different instrument systems are, in addition, distinguished by the fact that mea-

TABLE 1

SUMMARY OF ORTHOPHOTO DEVELOPMENT

Designation	*Year*)*	*Reference*	*Type*
Lacmann	1931	[1]	Optical projection, with sharp imagery
Ferber	1933	[2]	Optical projection, with sharp imagery
Bean (Orthophotoscope) with several successive models	1955	[3]	Optical projection ,with depth of field
FT-Schtsch	1959	[4]	Optical projection, with sharp imagery
Integrated Mapping System	1961	[5]	Image transfer by means of cathode ray tubes
Digital Automatic Map Compilation	1962	[6]	Image transfer by means of cathode ray tubes
Automatic Map Compilation System and Automatic Stereomapping System (Ramo-Wooldridge)	1963	[7]	Image transfer by means of cathode ray tubes
Stereomat (Hunting/Raytheon)	1963	[8]	Image transfer by means of cathode ray tubes
GZ 1 Orthoprojector (Zeiss)	1964	[9]	Optical projection, with sharp imagery

*) The years refer to the respective publications. On the majority of these developments, there are several, partly preceding publications.

suring process and exposure are either simultaneous or successive due to the use of memory devices. For the instruments based on a direct, optical reconstruction of the path of rays, solutions incorporating two projectors as well as others using three rigidly connected projectors are applied. The storage mediums used are cardboard templets, pencil lines, punched paper tape, magnetic tape, and scribed profile lines. Dropped-line contour charts are produced in addition to the orthophotogram proper. In the American systems, particular importance is attached to replacing the human operator by photo-electric scanning systems for elevation determination. An interesting summary of the work of about 35 years ago will be found on pages 83 to 88 of Schwidefsky 1935.[9] A review of American developments is given by Cude 1962[10] and others.

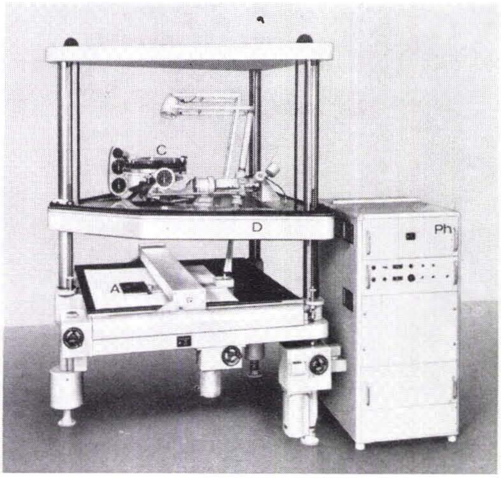

FIG. 2. GZ 1 Orthoprojector. The cabinet on the right houses the scanning and control elements required for operation by the "storage technique."

THE GZ 1 ORTHOPROJECTOR

Upon the initiative of Prof.-Dr. E. Gigas, work on such a development project was resumed in Germany also. The instrument (designed at Oberkochen), which in its basic design follows *Lacmann's* original ideas very closely, was primarily influenced in the practical stage by suggestions from H. Utz.

The working principle of the Orthoprojector (Figure 2) is obvious. The system of spatial coordinates is subdivided into the x,y-motion of the exposure slit A and the z-motion of the projection system C. This projection system is made up entirely of original components of the C8 Stereoplanigraph, namely:

(a) plotting camera including plotting lens and aspheric correction plate;
(b) spot-light follower illumination; and
(c) Bauersfeld auxiliary lens system.

The inclusion of an auxiliary lens system in the design of the instrument satisfies the demand for truly sharp imagery in the entire range of magnification, and includes large lens aperture for short exposure times with low-power lamps. In addition, the separation of plotting instrument and projector, as well as the use of purely optical methods, make it possible to employ both standard black-and-white material and color photography.

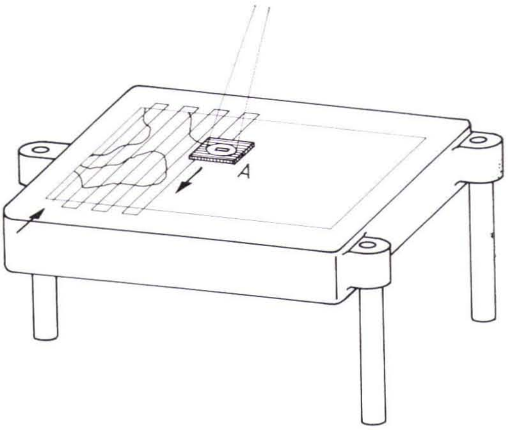

FIG. 3. Parallel travel path of the exposure slit during orthophotoscopic rectification

In operation, the exposure slit A of the Orthoprojector travels parallel strips across the projection surface (Figure 3). Its traveling speed in y-direction is uniform, but variable with the aid of pairs of change gears; x-steps are of equal size in one plot, but variable by appropriate means. The exposure is made without any overlap between strips. Consequently, the size of the selected x-step must correspond very exactly to the width of the slit in x-direction.

Usual strip widths are about 4 mm. if the maximum enlargement of projection of approximately 4× is used. The width of the slit in y-direction depends on the speed of the emulsion, the illumination system, and the selected traveling speed of the slit in y-direction. Table 2 shows values which are frequently used for practical work, and which may serve as an approximate basis for general considerations:

TABLE 2

AN EXAMPLE OF FILM TRAVEL SPEED, SLIT WIDTH, FILM EMULSION, AND ILLUMINATION

Travel speed of slit in y-direction:	5 mm./sec.
Width of slit in y-direction:	2 mm.
Photographic material:	Agfa halftone process film B/blue
Illumination:	6 V, 15 W incandescent projection lamp

While the exposure slit A travels along its parallel set of strips, the scale of the projected image is continuously varied in accordance with the relief of the terrain by the z-motion of the carriage D which holds the projection system. Further functions, such as the control of the positive lens carriage in the auxiliary system, the coordination between illumination and pupil of the projection lens, as well as the position of pivots and principal points determining optical independence, follow well known principles.

At the present time two different possibilities exist for driving the Orthoprojector. In the first method (Figure 4), GZ 1 and plotting instrument are connected mechanically or through selsyn systems in x, y and z. The plotter operator controls only the z-motion by keeping the floating mark in contact with the surface of the terrain model, which incidentally has been oriented in the normal manner. Any instrument may be used as a plotter, provided that it is sufficiently accurate and that it is driven in x, y and z by screws. The projector tilts ϕ and ω as well as the other initial values (x_0, y_0, z_0) are determined in the plotting instrument and set on the GZ 1.

STORAGE TECHNIQUES

In the second method (Figure 5), the operator records the values determined in the plotting instrument in a store S. This storage is effected in the form of scribing. At a later convenient time, these values are photoelectrically scanned in the correct correlation of x, y and z in the control unit Ph. This process of automatic readout and the respective exposure takes about two hours per model.

As compared to the "direct method," the "storage method" offers the following advantages:

(a) Plotting instrument and Orthoprojector may be operated at different speeds.

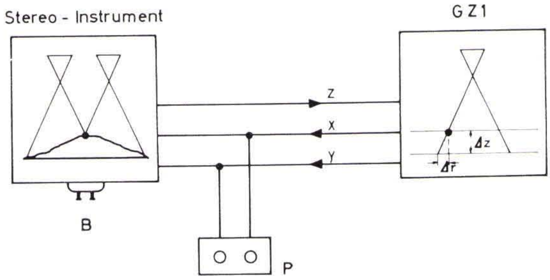

FIG. 4. Operation of Orthoprojector by "direct method."

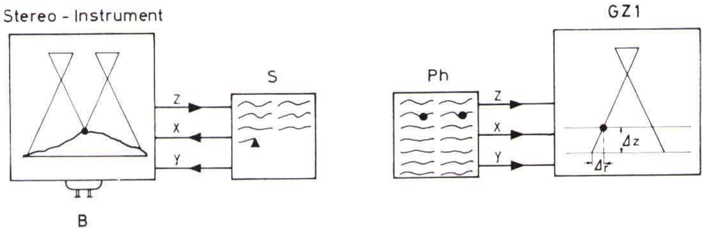

FIG. 5. Operation of Orthoprojector by "storage method."

(b) Erroneous measurements can be erased in the store and repeated without destroying all previous measurements.

(c) In the control unit, additional information can be taken over from the store, so that, for example, the so-called mismatches caused by residual errors of measurement and the slope of the terrain can be reduced by interpolation processes.

(d) Several plotters with store can be used to drive one GZ 1 instrument, since more time is required for measurement than for exposure.

(e) If re-flights are made years later, for instance for map revision, the respective storage plates can be reused, provided that the flights are designed accordingly.

These advantages can be obtained by a certain increase in the instrumental means employed. Figure 2 shows the control unit used in the storage methods at the right beside the Orthoprojector proper.

Figure 6 shows the combination of a C8

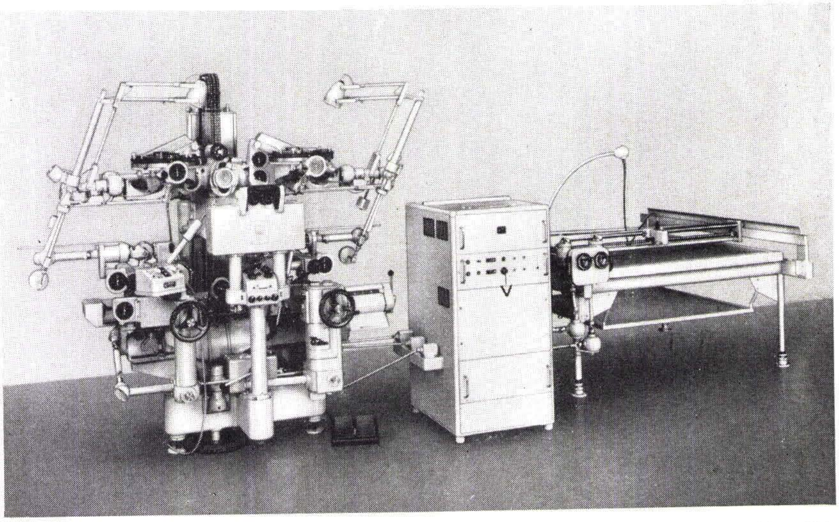

FIG. 6. C8 Stereoplanigraph with coupled storage device for recording of terrain profiles. The operator controls only the z-drive, while x and y are fed automatically. The knob v serves to select the traveling speed in y-direction.

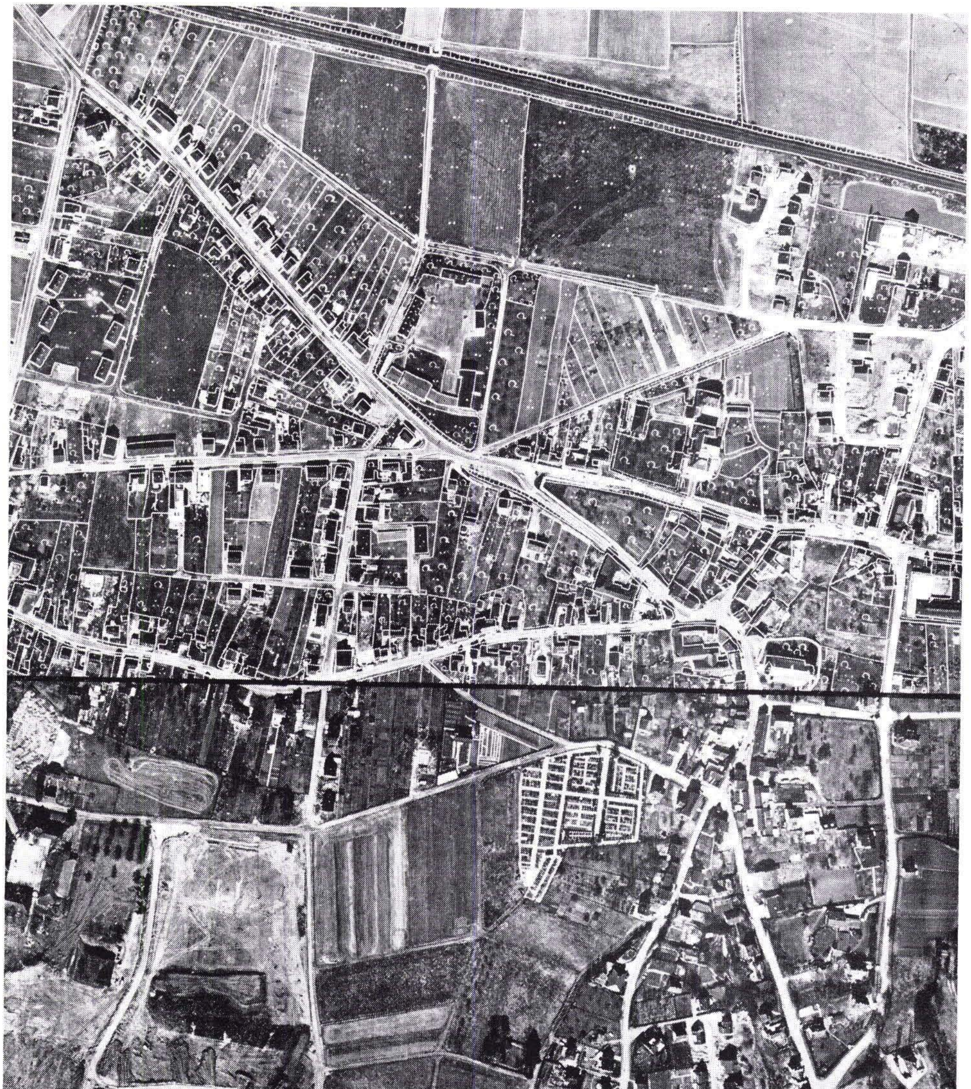

FIG. 7. Section of an orthophotograph prepared by means of Gigas-Zeiss GZ 1 Orthoprojector. Scale—1:6,500

Stereoplanigraph with the storage unit required for the storage technique.

With the technical means presently available, a further perfection of these techniques to allow the human operator *B* to be replaced by an automatic photoelectric scanning system is only a question of expense (an example is the Stereomat of the Raytheon Company). The limits of economy in the use of such auxiliary devices are reached in such cases where the automat depends to a large extent on human intervention (human memory).

Results

Figure 7 shows a section of an orthophotogram produced in the GZ 1 as an example. It was obtained by the first of the aforementioned two methods, that is, with GZ 1 directly coupled to the plotter. In studying this orthophotogram, special attention should be given to image quality, to possible variations in density between the different exposure strips, to disturbing lines between the strips, and to mismatches, i.e., a displacement of normally continuous lines at the edges of the strips. (The printed reproduction can naturally not show all the details in the same quality as the original orthophotogram.)

Photomaps thus obtained may become an interesting aid in the preparation of geodetic maps. A few printed photomaps have already been published in the United States. Another important example is the economic map of Sweden. The use of these photomaps for map revision opens up additional, interesting possibilities, above all in connection with the storage procedure, because the original map to be revised can be placed on the latest "map-like" aerial photographs and the changes entered by simple drafting techniques.

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