Methods and Instruments for the Production of Photo Maps

By Hans W. Faust
Carl Zeiss Oberkochen
West Germany
Commission IV

1. Introduction

Photo maps are rectified photographs to which some additions such as frames, sheet designations, place names, contour lines etc. are made. The photographs are generally rectified by photographic methods and optical means. If the terrain is even, the photo map can be exposed as a whole (simple rectification) but if the terrain is hilly or mountainous, the photo map has to be exposed in parts. Carl Zeiss, Oberkochen, offers instruments suited to both methods: The SEG 6 for simple rectification and the Z 2 Orthocomp orthoprojector for differential rectification. Both instruments have been used successfully in many parts of the world for the production of photo maps. Even so the instruments are continually being improved and matched to new or changing requirements. The improvements made since the 1980 ISPRS Congress in Hamburg are described in this paper (sections 2 and 3). Also, instrument users communicated experiences and asked questions which might be of general interest. So sections 5 and 6 deal with questions concerning photo map precision and photographic methods.

2. Simple Rectification

Simple rectification of aerial photography generally serves to achieve the desired scale and to correct the distortions caused by camera tilt. Distortions due to differences in elevation in the photographed terrain can be corrected only in special cases. The SEG 6 rectifier was developed by Carl Zeiss for simple rectification. Development work began in 1937 and was continued with the SEG 5 (1955) and the SEG 6, which was presented in 1978 (Meier 1969, Hobbie 1976, 1978).

The major features of this instrument are:

- High-resolution and virtually distortion-free TOPOGON 5.6/180 lens

- Automatic focusing and automatic control of the table tilt and the photo-carriage tilt according to the Scheimpflug condition.

- Automatic control of table tilt and photo shift (vanishing point control)

- Numerical orientation by digitizer and desktop computer (OCS 1 orientation system optional)

- Illumination with Fresnel lens condenser and automatic lamp position control according to magnification.

The light source is a 125 W mercury vapor lamp for black-and-white work. For color work, the mercury lamp had up to now to be replaced by an incandescent lamp. A set of 400 mm x 400 mm gelatine filters was available for color correction.

On the occasion of the 1984 ISPRS Congress, a new illumination system is presented which replaces the previous illumination system for color material. This illumination system was developed in cooperation with the DURST Company. It is a combination of the COLIKIT 2000 illumination system for DURST enlargers with the SEG 6 Rectifier. This rectifier configuration is called SEG 6 C. Fig. 1 shows the prototype of the SEG 6 C. The light source is a 2000 W halogen lamp which can also be operated with only 1000 W. Instead of a lens condensor, a concave mirror and several cascaded diffusers are used. Between the diffusers there are continuously adjustable dichroic color filters (magenta, cyan, yellow) and an aperture which is also continuously adjustable. Table illumination in the SEG 6 C is as bright as with the previously used illumination system for color work, namely about 20 lux in the center at 2x magnification and f/5.6. The SEG 6 C can also be used for black-and-white work, of course; in this case the filters can be used for work with gamma-variable material (see section 5). Compared to the illumination system of the SEG 6 with mercury vapor lamp and "dense" diffuser (half-intensity angle 4^{o}), table illumination is about twice as high in the SEG 6 C, and compared to the SEG 6 without diffuser it is about 3 times less. The new illumination system has proven itself not only in many professional enlargers made by DURST but has also been used in an SEG by HANSA LUFTBILD in Münster, West Germany, for several years. Wide-angle (c=153 mm) size 23 cm x 23 cm photographs are fully illuminated at all table tilts and corresponding shifts. With photography taken with other focal lengths, the illuminated field might be reduced if extreme table tilts are used.

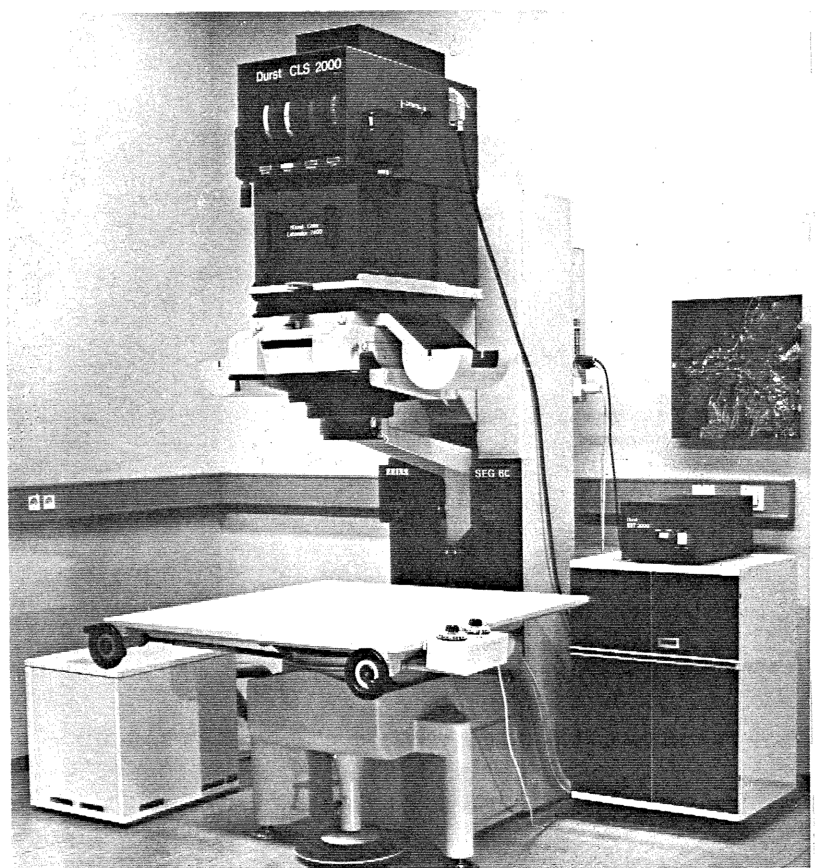

Fig. 1: Prototype of the SEG 6 C with new illumination system

3. Differential Rectification

In instruments using differential optical rectification, the photo map is exposed in strips through a slit aperture. A small section of the photograph to be rectified is projected onto the slit with continuously changing magnification and rotation. The magnification and rotation data is obtained from data on the camera orientation at the time the photograph was taken and from terrain elevation data. Modern optical orthoprojectors are equipped with zoom lenses and an image rotation prism. The zoom lens and the prism as well as the photo position and the film position relative to the slit aperture are controlled by a digital computer.

Fig. 2: Z 2 Orthocomp with HP 1000 computer terminal

The Zeiss Z 2 Orthocomp (Fig. 2) orthoprojector (Faust 1980, Hobbie, Faust 1983) uses this principle.

The major features of the Z 2 Orthocomp are:

- Parallel profiles with x, y, z terrain or model coordinates can be used directly for control (use of existing data bases, repeated use for map revision with new photography).

- Point distances in the profiles and the profile spacing may be random and may differ within a set of profiles (the point and profile densities can be matched to the terrain conditions).

- If the elevation data is not available in the form of profiles, profiles can be computed with the HIFI-P program (Ebner et al., 1980, Ebner, Reiss 1984) from randomly distributed elevation data. This program was written for the HP 1000 computer which controls the orthoprojector (use of contour line data and of progressive sampling data or densification of profile data; Ebner, Reinhardt 1984).

- The orientation data of the photograph to be rectified can be determined with the orthoprojector if the x, y, z ground coordinates of at least 3 control points are known (no preparatory measurements at a stereoplotter).

- After photo map exposure, letters, numbers and symbols can be exposed on the photo map with the orthoprojector (map sheet corner and control point symbols for checking the precision, labels in the map or on the frame).

The orthoprojector was presented in 1980 at the 14th ISPRS Congress in Hamburg with these features which make the instrument an "analytical orthoprojector".

The HP 1000 minicomputer made by Hewlett-Packard has been selected for controlling the Z 2 Orthocomp orthoprojector, initially with a type E or F processor and the RTE 4 B operating system.

At the 1984 ISPRS Congress at Rio de Janeiro the Zeiss Z 2 Orthocomp is presented with the new HP 1000 A series computers and with a series of new programs and program improvements that were developed during the last four years.

- Programs for the production of stereo orthophotos (Ebner et al.). The HIFI-S program computes control profiles for stereo mates with artificially introduced x parallax which depends either linearly or logarithmically on the terrain elevation and can be computed either for the left or the right stereo mate. An addition to the Parameter program of the Z 2 relates the stereo mate profiles to the terrain profiles. The precision of the artifical parallaxes in the finished stereo mate has been investigated by E. Clerici (1983).

- The HIFI-3D program was developed by H. Ebner et al. for representing digital elevation models in perspective either on a graphics CRT terminal or a plotter (Clerici 1983). Such representations allow fast plausibility checking of profile data computed with the HIFI-P program, whose accuracy depends on the quality and distribution of the input data used with HIFI-P.

- Profile data checking is also performed by a program extension which is presented here for the first time: When the profile data is read into the scratch file, the data is checked for transgression of a selectable terrain slope, for exceeding or falling short of selectable terrain elevations (Hmax, Hmin), and for spikes at isolated points.

- Transfer programs for blocked profile data:
  The GREAD program allows taking advantage of the high packing density of blocked magnetic tape storage. It transfers data sets with up to about 32 700 points into a general file, from which the profile data can be read into the scratch file with the standard Z 2 programs and be checked for errors and pausibility. The partner of the GREAD program is the GWRIT program which transfers data from a general file to magnetic tape using optional blocking factors. GREAD, GWRIT and the GEFIL editing program form a package called GEFIO (General File Input/Output).

  For data sets which exceed the general file capacity of about 32 700 points, another program was written which transfers data directly from magnetic tape to the Orthocomp scratch file and allows the capacity of the latter of 120 000 points (300 profiles with 400 points each) to be fully used. However, this program requires the data to be error-free because the checks made by the Parameter program are skipped.

- Another new program allows the Orthocomp orthoprojector to be used as a medium-precision monocomparator in case the instrument should not be fully loaded by photo map production. Either carriage coordinates or photo coordinates (referred to the fiducial marks of the photo) are measured and put out on a printer or magnetic tape unit.

- Finally, a small but useful program was written for preparing orthophoto parameters in an ASCII file.

Apart from the monocomparator program and the profile data transfer programs, the programs can all be processed in parallel with preparing and exposing a photo map if another terminal is connected to the computer.

4. Precision

When preparing for simple rectification, the rectifier can be set up with an existing map or a control point plot. The photo map precision can then be assessed directly by comparing the rectified photo with the control points or the map. When differential rectification is being prepared, an optical image of the complete photo map that could be compared with a map or a control point plot is not available. The orientation program of the Z 2 Orthocomp allows the residuals at up to 10 control points to be computed, but this is only one of the factors affecting the precision of the photo map, namely interior and exterior orientation. Another factor is the quality of the terrain model represented by the control profiles. If the terrain model elevations deviate from the actual terrain elevations, planimetric displacements occur which cannot be detected while rectification is being prepared.

Even if only graphical precision is expected of the photo map, planimetric displacements are rather annoying at the map edges where the adjacent sheets should match precisely. What is worse is that elevation model deviations from actual terrain elevations cause particularly large planimetric displacements especially at the photo edges: In the corners of a wide-angle photograph an elevation deviation causes a planimetric displacement of about the same size in the terrain scale. Of these displacements, only those components affect the matching of adjacent sheets which are parallel to the line connecting the perspective centers of the two photographs.

However, these displacements are mutually opposing in the adjacent sheets, i. e. they add up. If mismatches of not more than 0.3 mm are tolerated for adjacent sheets, the elevation deviations of the terrain model must not exceed m_k * 0.3 mm/$\sqrt{2}$, i. e. about 2 m for a map scale of 1 : m_k = 1 : 10000. This includes deviations due to linear interpolation between the terrain model points (see below).

On the other hand, planimetric displacements in the photo map need not always be errors. High points like tree tops for example are displaced in plan if the ground level terrain elevation is used for rectification.

It may therefore be sensible not to use the ground level elevations but the tree-top level elevations for rectification when photography of a wooded area has to be rectified to ensure that adjacent sheets of the photo map match properly.

Deliberately not using the ground level elevations may also be sensible when break lines have to be rectified differentially. Break lines which are oblique relative to the profile direction appear as wavy lines during differential rectification. The wavelength is either twice the profile distance or twice the slit aperture length depending on which value is greater. Even if the smallest slit aperture (2 mm) and the corresponding profile distance are used, the amplitude may be so large that a bad impression is created. Such faults can be avoided by means of terrain models which suppress break lines more or less.

Apart from these deliberate planimetric displacements, all non-intentional displacements must be considered as errors. They are caused either by deviations of the elevation data from the actual terrain data or by linear interpolation between profiles and profile points. Linear interpolation is used to approximate the terrain by means of facettes. The facette edges are straight lines which need not be located in the same plane. The elevation deviations caused by this approximation depend on the curvature of the real terrain, i. e. not on the differences in elevation and not on the slope angle of the terrain. A tortuous terrain with differences in elevation of only 10 m may have to be measured with a denser grid than a high-mountain area featuring differences in elevation of several 100 m and large slope angles.

The amount of planimetric displacement caused by elevation deviations depends on the distance from the sheet center. Near the center, elevation deviations cause only small planimetric displacements. This is why much larger grids can be used for elevation measurement near the photo center than for elevation measurement near the edges (Ellenbeck, Tönnessen, 1981).

5. Photographic Methods

5.1 Black-and-White Photo Maps

For series production of photo maps, for example, rectified negatives with an optical density between 0.3 and 1.4 are produced (Krauss, Pape 1973). To obtain products which are consistently in the desired density range, a certain amount of standardization is required also during preparation of the photographs to be rectified. This includes dodging to standard minimum and maximum optical density values.

It has been found opportune, for example, to prepare air photo diapositives with densities of 0.5 to 1.1 when rectified negatives with densities of 0.3 to 1.4 are to be produced with the Zeiss SEG (Krauss, Pape 1973). These density values apply to diffused light. Orthoprojectors generally use strongly focused light which, through Callier's effect, increases the density and also the contrast. For example, density values of 0.7 to 2.3 were measured with the densitometer of the Orthocomp with finegrain reproduction film while density values of 0.3 to 1.3 were obtained with the same film when diffused light was used for measurement.

The purpose of the built-in densitometer is to allow density measurement under the lighting conditions used for exposing the orthophoto. To compensate Callier's effect, air photography to be used for differential rectification should be prepared so that the optical density is lower when measured with diffused light (e. g. 0.1 to 0.7 with the above-mentioned film) than photography to be used for simple rectification with the SEG 6.

If optimum preparation of aerial photography is not possible or not desired (e. g. because original air photo negatives are to be used for photo map production), the photo map contrast can be controlled with gamma-variable emulsions. Such photographic material is available from Agfa-Gevaert (GO films), Dupont (CCV film) and Ilford (multigrade paper), for example. These black-and-white emulsions allow the slope of the film characteristic, i. e. the gamma value, to be influenced by the color of the light. The use of such an emulsion with the SEG 5 rectifier was described some years ago already (Tönnessen, Stöckler, 1979). Color adjustment is particularly convenient with the new illumination system of the SEG 6 C (see section 2). This instrument was used to expose the GO 210 p film with blue filtering (100 magenta + 130 cyan) for gamma = 0.7 and with yellow filtering (130 yellow) for gamma = 1.7 (exposure time 3 seconds with f/16, magnification ratio 1 : 1).

The Z 2 Orthocomp orthoprojector allows the light color to be modified with gelatine filters. Up to three filters can be combined. However, if all of the contrast increase caused by Callier's effect is to be compensated by means of gamma-variable material, strong filtering is required so that the film drum speed may have to be reduced.

5.2 Rectification with Color Film

When color film is used, it is nearly always necessary to compensate color deviations by filtering. Which filters have to be used has to be determined by means of tests. Because of atmospheric haze, different filtering may be required for the corners than for the centers (Meier, 1967). With simple rectification this is relatively easy by exposing the corners again with another filter combination. Also, test exposures can be made quickly with the SEG 6. An advantage of the SEG 6 C is that the color can be adjusted continuously and with a high repetition precision at the new illumination system.

During differential rectification with an orthoprojector the total exposure time is rather long compared to a rectifier so that making a series of test exposures with different filtering is time-consuming. Also, exposing the corners again with a different filter combination is virtually impossible.

This is why an intermediate product approach is generally used for differential rectification. The intermediate product is a color negative or diapositive exposed with the orthoprojector that is produced without or with only little compensation filtering. The final products are made from this intermediate product by contact printing with color correction. Proven film material for this aproach are Kodak Vericolor film for positives to negatives or negatives to positives and Ektachrome duplicating film for positives to positives or negatives to negatives as well as the associated paper types.

A new paper material for positive to positive processes is the Agfachrome Speed Paper produced by Agfa-Gevaert. Tests have been performed exposing this type of paper on the SEG rectifier as well as in the Z2 Orthoprojector.

6. Conclusion

The Zeiss SEG 6 C and the Z 2 Orthocomp are state-of-the-art instruments for photo map production by simple and differential rectification. Both instruments convert aerial photography to photo maps by optical means and with high resolution so that the improved photo quality obtained with state-of-the-art cameras (Meier 1984) can be used fully for photo map production.

Abstract

The SEG 6 and the Z 2 Orthocomp available from Carl Zeiss, Oberkochen, for the production of photo maps by simple and differential rectification. Both instruments have been improved during the last years. The SEG 6 C has been equipped with a state-of-the-art illumination system for color and black-and-white work. New programs have been written and program improvements made for the Z 2 Orthocomp and the new HP 1000 A series computers. These developments are described and some aspects of photographic methods and the precision of photo maps are discussed.

Literature

Clerici, E.: Production of Stereo Orthophotos with Analytical Orthoprojection. Photogrammetric Week 1983, Publications of the Institut für Photogrammetrie of Stuttgart University, Volume 9 (1984)

Ebner, H., Hofmann-Wellenhof, B., Reiss, P., Steidler, F.: HIFI - A Minicomputer Program Package for Height Interpolation by Finite Elements. 14th Congress ISPRS 1980, Comm. IV, and Zeitschrift für Vermessungswesen 105, 215 to 225 (1980)

Ebner, H., Reiss, P.: Experience with Height Interpolation by Finite Elements
To be published in Phot. Eng. 50 (1984)

Ebner, H., Reinhard, W.: Progressive Sampling and DEM Interpolation by Finite Elements. 15th Congress ISPRS, Comm. IV, and Bildmessung und Luftbildwesen 52 (1984)

Ellenbeck, H. K., Tönnessen, K.: Datengewinnung für analytische Orthoprojektion durch Digitalumsetzung von GZ 1 - Speicherplatten. Bildmessung und Luftbildwesen 49, 1 to 7, (1981)

Faust, H. W.: Z 2 Orthocomp, The Analytical Orthoprojector from Carl Zeiss. 14th Congress ISPRS 1980, Comm. II, and Bildmessung und Luftbildwesen 48, 110 to 118 (1980)

Hobbie, D.: Orthophoto Project Planning.
Phot. Eng. 40, 967 to 984, (1974)

Hobbie, D.: Numerische Einpassung am Entzerrungsgerät SEG 5 mit der Orientierungseinrichtung Zeiss OCS 1. Bildmessung und Luftbildwesen 44, 164 to 168 (1976)

Hobbie, D.: Das Zeiss-Entzerrungsgerät SEG 6. Bildmessung und Luftbildwesen 46, 16 to 20 (1978)

Hobbie, D., Faust, H. W.: Z 2 Orthocomp, The New High Performance Orthophoto Equipment from Zeiss.
Phot. Eng. 49, 635 to 640 (1983)

Krauss, G., Pape, E.: Experience in the Production of 1:5000 Photo Maps in North Rhine-Westphalia. 7th Regional Cartographic Conference of the United Nations for Asia and the Far East, Tokyo 1973

Meier, H. K.: Farbtreue Luftbilder? Bildmessung und Luftbildwesen 35, 206 to 214 (1967)

Meier, H. K.: Die Entwicklung im photographischen Instrumentenbau während der letzten 30 Jahre, dargestellt am Beispiel der Zeiss-Geräte. Zeiss-Mitteilungen 5, 105 to 127 (1969)

Meier, H. K.: Progress in Improving the Performance of Zeiss Aerial Cameras. 15th Congress ISPRS, Comm. I (1984), and Bildmessung und Luftbildwesen 52 (1984)

Tönnessen, K., Stöckler, H. P.: Belichtungssteuerung zum Entzerrungsgerät SEG 5. Bildmessung und Luftbildwesen 47, 143 to 147 (1979)