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THE PRODUCTION OF STEREO-ORTHOPHOTOS WITH ANALYTICAL ORTHOPROJECTION

E. Clerici, Oberkochen

1. Introduction

The present generation of computer controlled orthophoto equipment offers simple, flexible and fast procedures for the production of high quality orthophotos (Faust, 1980). Flexibility and quality have somewhat revived the market interest in the stereo-orthophoto: stereo-partners can now be produced in a simple and straight forward manner as a by-product of the orthophoto itself. The inherent instrumental accuracy allows heights to be determined from parallax measurements with a very high degree of precision.
This paper describes the production process of stereo-orthophoto with the analytical orthoprojector Orthocomp Z-2 and documents test results on the achievable accuracy.

2. Historical background

The idea of producing stereo partners to an orthophoto dates back to the 60's (Collins, 1967), where the technique was seen as a natural complement to the orthophoto so that "a three dimensional visual model of the terrain and surface details was possible" and "simple and direct methods of measuring distances, elevations and slopes with inexpensive equipment" would be feasible (Collins, 1967). Indeed an instrument to restitute stereo-orthophotos was patented in Canada in 1970 (Blachut, 1970), more recently a similar instrument has also been produced in Europe (Kraus, 1981).
Practical applications of the stereo-orthophoto as such could be envisaged in different fields of Earth sciences where the interpretation of an orthophoto could be enhanced by stereoscopic viewing and where quantitative height information is needed from relatively simple means, for example by mirror stereoscope and parallax bars.
Reports of operational use of stereo-orthophotos however are not easy to find, although Kraus (1981) does mention that "hundreds of stereo-orthophotos have been produced for Austrian users and for foreign contractors." No mention was made of the fields of their applications, however.

3. The geometric principle of the stereo-orthophoto

The geometric principle of the stereo-orthophoto is quite simple and as old as photogrammetry itself: features in the stereo-partner should be displaced in the direction of the observing eye-base with respect to the position of their corresponding points in the orthophoto. The resulting "x-parallax" should be proportional to relative height differences.

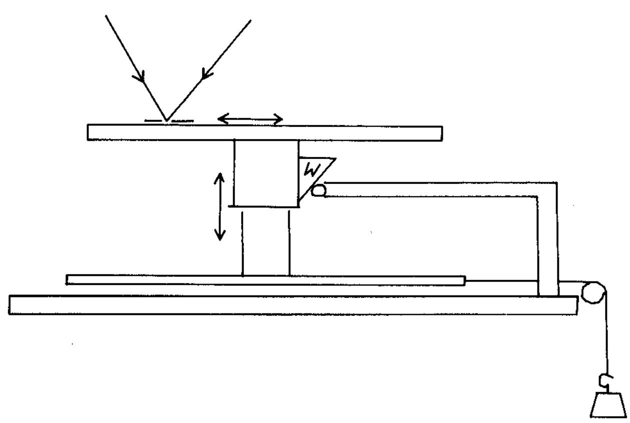

Fig. 1: Adaptation of the SFOM orthoprojection table in the first stereo-orthophoto instrument (Collins, 1967)

It is quite illustrative to see how the original instrumental implementation of the idea was realized; this is illustrated in fig. 1: a linear cam "w" shifted the exposure plane of a SFOM orthophoto table in x-direction as this was moved up-and-down during the scanning process in a Kelsh plotter.
In the analytical orthoprojector Orthocomp Z-2, artificial x-parallaxes for the stereo-partner are obtained by transformation of the x and z coordinates of the original orthophoto profiles according to a linear or to a logarithmic projection. Fig. 2 shows the geometric relation upon which the linear transformation is based.

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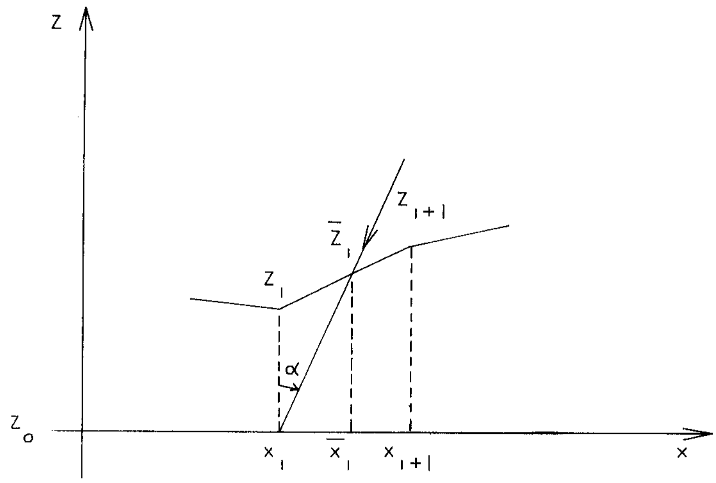

Fig. 2: Geometric principle of linear projection

In the figure above, xi and zi are the coordinates of a point i in the orthophoto profiles, $\bar{x}$i and $\bar{z}$i are the coordintes of a point in the stereo-partner profiles, k is the chosen (artificial) photo base / height ratio and "alpha" is the angle of projection.

The transformation formulae according to the linear projection are as follows:

$$\bar{x}_i=((x_{i+1}-x_i)(x_i+kz_i)-x_ik(z_{i+1}-z_i))/(x_{i+1}-k(z_{i+1}-z_i)-x_i)$$

$$\bar{z}_i=z_i+(z_{i+1}-z_i)(\bar{x}_i-x_i)/\ (x_{i+1}-x_i)$$

For a natural stereo impression the value of k should be chosen between 0.5 and 0.6. For flat terrain the value of k=0.8 is recommended.

The height of an arbitrary point i can be obtained as follows:

$$h_i=p_i/k+z_0$$

where p_i is the measured x-parallax and z_0 is the height of a reference plane above datum.
The transformation according to the logarithmic projection is based on:

$$\bar{x}_i=x_i+B\ln(H/(H-\bar{z}_i))$$

The height of an arbitrary point i can then be computed by the relation:

$$h_i=H(1-\exp(-p_i/B))+z_0$$

where H and B are, respectively, the computational flying height and the base.

4. Production process with the Orthocomp Z-2

The actual procedure for obtaining a stereo-partner with the Orthocomp Z-2 is essentially identical to the production of conventional orthophotos, since this has been described in some detailes elsewhere (Faust, 1980), only the functional step will be given here:

- measurement of Digital Height Model (DHM) : random points sequence, profiles, grid, contours.
- computation of orthophoto profiles using the interpolation program HIFI (Ebner et al. 1980)
- computation of the corresponding stereo-partner profiles using the HIFI-S program module of the above package. These profiles are obtained according to the geometric description given in (3).
- interpolation of instrumental control profiles as function of the chosen projection slit length.

During implementation of the last three steps at the Orthocomp's terminal, the operator is guided by interactive dialogue at the screen (see fig. 3). The procedure differs from the conventional orthophoto production one only by the answers given to a few of the questions in the dialogue.
This mode of operation has been well accepted in practice; training time in the

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use of the equipment, even to relatively inexperienced operators, is remarkably short.

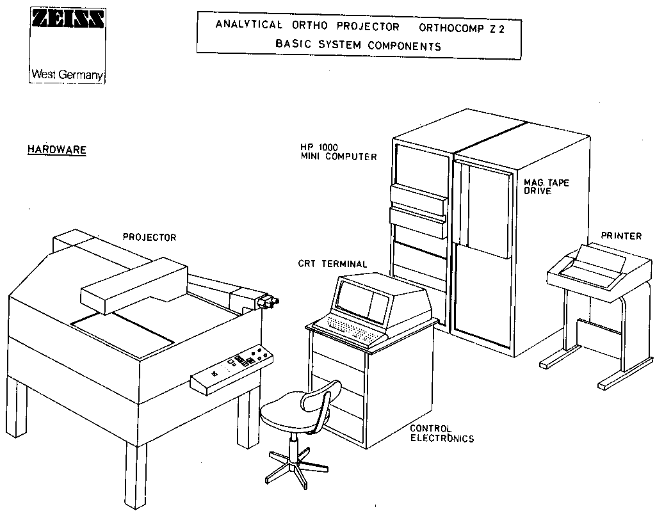

Fig. 3: View of the Orthocomp Z-2

5. Assessment of the instrumental accuracy

An empirical way in the form of a control test with simulated data, was chosen to assess the geometric quality of the stereo-orthophoto obtained with the production process described above. The geometric quality is quantified here by the height accuracy obtained from parallax measurements.
By using a controlled test with simulated data, there is no random component in the input and in the data taken as reference, hence the accuracy of the output is only influenced by the errors introduced at the various phases of the production process. In this case the instrumental accuracy was of primary interest, other possible error sources were minimized by choosing appropriate parameters and production procedures as indicated here:

- error due to DHM interpolation was minimized by choosing a dense set of reference points and an appropriate interpolation procedure (HIFI-P)
- error due to the interpolation of the control profiles was minimized by chosing a narrow slit length (2mm.)
- error due to x-parallax measurements was minimized by measuring the x-coordinates with an instrument whose accuracy is well above the expected instrumental error of the orthoprojector (Planicomp)

The test area used simulated rather extreme conditions for orthophoto production (see fig. 4)

The following project parameters were related to the test area:

focal length	150 mm.	omega (gon) -2.355
mean flying height	2000 m.	phi (gon) 4.424
mean ground height	350 m.	kappa (gon) -9.870
variation in ground heights	33%	9 control points
orthophoto scale	1:10000	sigma naught=0.025 mm.

The photographic input of the test area was a grid (see fig. 5) resulting by central projection of corresponding (equally spaced) points in the DHM, and obtained with the indicated project parameters.
The input just described is regularly used for one of the acceptance tests for the Orthocomp Z-2.

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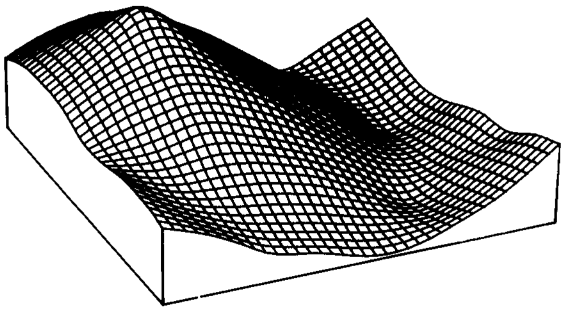

Fig. 4: Perspective view of simulated DHM computed with HIFI-3D

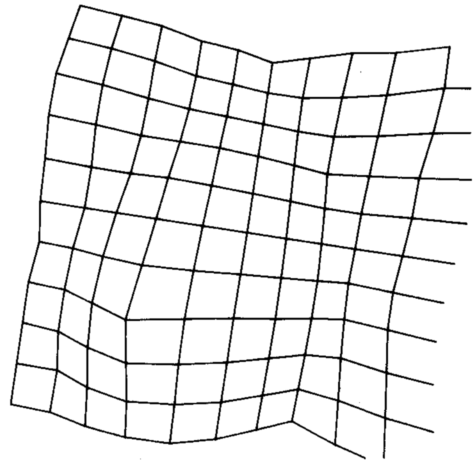

Fig. 5: Photographic input of grid corresponding to the DHM of the test area

The x-parallax of 45 grid points in the orthophoto-stereopartner combination resulted in a mean square error in height of 0.95 m. which corresponds to less than 0.1 per cent. of the mean flying height. The associated x-parallax mean square error is 0.05 mm. in the orthophoto. This error includes primarily the inherent instrumental error, however residual errors due all other possible error sources in the process are still present.

6. Conclusions

Production of stereo-orthophotos with analytical projection is today a fast and simple procedure with high quality output.
There is no doubt that the additional height information from the stereo-partner (quantitative or qualitative) can be of use to a number of orthophoto users. The extent of the application of stereo-orthophotos seems to depend, like for all other commodities, on how well the photogrammetrist in government or in private practice can "sell" this technology to its potential users.

7. Literature reference

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Abstract

After a brief review of the principles and the background of stereo-orthophotos, the paper describes the process of stereo-orthophoto production by analytical orthoprojection.
An empirical assessment of the achievable geometric accuracy using the Zeiss Orthocomp Z-2, indicates that the inherent instrumental errors allow heights to be determined from parallax measurements with an accuracy which is better than 0,1% of the mean flying height.

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ZUSAMMENFASSUNG
DIE HERSTELLUNG VON STEREO-ORTHOPHOTOS MIT ANALYTISCHER ORTHOPROJEKTION

Nach einer kurzen Übersicht von Prinzip und Hintergrund des Stereo-Orthophotoverfahrens beschreibt das Paper die Erzeugung von Stereo-Orthophotos mit analytisch-differentieller Entzerrung.
Eine empirische Untersuchung der erreichbaren geometrischen Genauigkeit mit dem Zeiss-Orthocomp Z-2 zeigt, daß die Gerätefehler die Höhenbestimmung durch Parallaxen-Messungen mit einer Genauigkeit erlauben, die besser ist als 0,1% der mittleren Flughöhe.

RESUME
PRODUCTION D'ORTHOPHOTOGRAPHIES STEREOSCOPIQUES PAR ORTHOPROJECTION ANALYTIQUE

Après une courte révision du principe et de l'historique des orthophotographies stéréoscopiques, le manuscrit décrit le procédé de la production analytique. Une évaluation empirique de la précision géométrique que l'on peut obtenir par l'utilisation de l'Orthocomp Z-2 indique que les erreurs propres à l'instrument permettent d'obtenir des cotes, qui doivent être déterminées à partir des mesures de parallaxe, avec une précision supérieure à 0,1% de la hauteur moyenne de vol.

RESUMEN
LA PRODUCCION DE ESTEREO-ORTOFOTOS CON AYUDA DEL ORTOPROYECCION ANALITICA

Después de exponer en una breve sinopsis el principio y el historical del método de las estereo-ortofotos, se explica en la presente conferencia su producción por medio de la rectificación analítico-diferencial.
Un examen empírico de la exactitud geométrica alcanzable con ayuda del Zeiss Orthocomp Z-2 permite demostrar que los errores instrumentales admiten la determinación de altitudes por medición de paralajes con precisión superior al 0,1% de la altura media del vuelo.

Dr.-Ing. Enrico Clerici, Firma Carl Zeiss
Geschäftsbereich Geodäsie und Photogrammetrie
Postfach 1380, 7082 Oberkochen