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THE DIGITAL ORTHOPHOTO MAP VERNAGTFERNER 1990[1]

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With 6 figures and 1 map supplement

ABSTRACT

The production of a high quality coloured orthophoto map Vernagtferner 1990 1 : 10,000 in the Ötztal Alps, Austria, was carried out by the Chair for Photogrammetry and Remote Sensing, Technical University Munich in cooperation with the Commission for Glaciology of the Bavarian Academy of Science. The necessary orthoprojection has been performed entirely in the digital domain. The high geometric quality of the underlying digital terrain model (DTM) could be preserved, because the hybrid vector-/raster data structure of the DTM was introduced for the orthoprojection. The resulting orthoimage was then superimposed with digitally generated height contours and combined with cartographic information. With this example in mind the obvious advantages of digital orthoprojection in comparison to analogue techniques, but also some encountered problems are discussed.

DIE DIGITALE ORTHOPHOTOKARTE VERNAGTFERNER 1990

ZUSAMMENFASSUNG

Am Lehrstuhl für Photogrammetrie und Fernerkundung der Technischen Universität München wurde in Zusammenarbeit mit der Kommission für Glaziologie der Bayerischen Akademie der Wissenschaften die hochqualitative farbige Orthophotokarte Vernagtferner 1990 hergestellt. Die notwendige Orthoprojektion wurde vollständig digital durchgeführt. Die hohe geometrische Qualität des zugrundeliegenden digitalen Geländemodells (DGM) konnte erhalten werden, weil die hybride Vektor-/Rasterdatenstruktur des DGM während der Orthoprojektion berücksichtigt wurde. Das resultierende Orthobild wurde anschließend mit digital erzeugten Höhenlinien überlagert und mit kartographischer Information kombiniert. Anhand dieses Beispiels werden die offensichtlichen Vorteile, aber auch einige Probleme der digitalen Orthoprojektion im Vergleich zur Analogtechnik diskutiert.

1. INTRODUCTION

Areas with an extensive snow and ice coverage are rather inaccessible for humans. Nevertheless, they constitute an important part for our life, e. g. in terms of climate and water storage. Therefore, there is a need for topographic information of such areas. Traditionally this information was depicted in paper maps. Today it is increasingly being stored in the data bases of geographic information systems (GIS). The most efficient way to collect the necessary data is photogrammetry and remote sensing. An excellent example is the work carried out at the In-

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stitute for Applied Geodesy (IfaG) for Antarctica (Bennat 1992). In the Alps and mountain ranges of comparable size and population density, the required geometric accuracy for topographic information is generally higher than in isolated areas such as Greenland or Antarctica. For example, individual glaciers and their movement need to be monitored.

The Vernagtferner in the Ötztal Alps, Austria, has been a preferred area of glaciological and photogrammetric research for more than one century. First activities date back to 1888/89 (S. Finsterwalder 1897). Many results of these efforts have been presented in this journal (see e.g. Brunner, H. Rentsch 1972, Rü. Finsterwalder 1972a, H. Rentsch 1982). Within this framework orthophotos have played an increasingly important role for glaciological mapping (e.g. Rü. Finsterwalder 1972b, Brunner 1976, H. Rentsch 1982).

This paper reports on a recent project carried out at the Chair for Photogrammetry and Remote Sensing, Technical University Munich, in cooperation with the Commission for Glaciology of the Bavarian Academy of Science and should be seen as a continuation of mapping activities of the Vernagtferner. Digital orthoprojection was employed to generate a highly accurate coloured orthophoto map 1:10,000 based on a high quality digital terrain model (DTM) with a hybrid vector-/raster data structure. The next chapter shortly reviews digital orthoprojection. Subsequently the actual work needed for the map production is described. Then, investigations of the orthophoto accuracy are presented. The last chapter contains some experience and conclusions gained in this project.

2. DIGITAL ORTHOPROJECTION – PRINCIPLES, POSSIBILITIES AND APPLICATIONS

In the transition from analytical to digital photogrammetry many conventional photogrammetric and cartographic tasks, which used to be carried out on special equipment, are integrated into digital photogrammetric systems, paving the way to automation. A good example is the orthoimage (digital orthophoto). First concepts go back to Kreiling (1975) and others, first applications could be found in the rectifications of satellite imagery (e.g. Konecny 1979). Today orthoimages are on the verge of becoming standard products of digital photogrammetry and can be computed rapidly and inexpensively (Bähr 1989, Höhle 1992, Kraus 1993) and form the base of orthophoto maps (Colomina et al. 1991).

Orthophoto maps contain a large variety of topographic information. In comparison to line maps, details are perceived much more realistically. Compared to analytical orthoprojection the digital way offers additional advantages. They are geometrically more accurate, since the underlying DTM can be considered in its full information content. The overall perception of the map can be easily enhanced, and important details can be made visible by means of image processing techniques. Furthermore, they can be introduced into the data bases of geo-information systems (e.g. Thorpe 1991, Baltsavias 1993). Other advantages include the stable image geometry and radiometry of orthoimages, electronic image transmission, and the possibility to produce an unlimited number of copies without quality loss. Software for digital orthoprojection is part of all major digital photogrammetric systems (e.g. Kaiser 1991, Mayr 1993a, see Heipke 1993 for an overview). The principles of digital orthoprojection can be found in the literature and shall only be reviewed briefly in this section. A detailed description of all aspects of digital orthoprojection can be found in Mayr (1993b).

In order to carry out a digital orthoprojection, for a given region the corresponding DTM and the digital image together with the orientation data have to be at hand. For the geometric projection from object into image space two major possibilities exist:

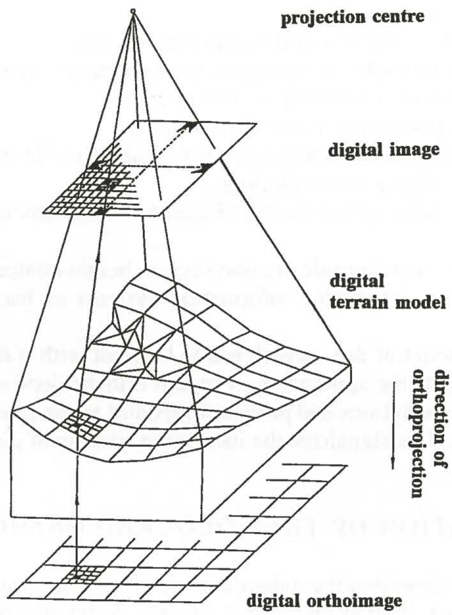

Fig. 1: Principles of digital orthoprojection

– the pixel-for-pixel method (e.g. Mayr, Heipke 1988), and
– the anchor point method (e.g. Wiesel 1985).

The pixel-for-pixel method constitutes a special case of the anchor point method. It provides the possibility to use the complete geometric information contained in a high quality DTM with hybrid vector-/raster data structure for the orthoprojection in an easy way. Figure 1 shows the procedure. First, the region for which the orthoimage is to be computed is defined in the XY-plane of the object coordinate system. This region is divided into orthoimage pixels of equal size. This size depends on the image scales of the original and the orthoimage. For each orthoimage pixel the corresponding height is interpolated from the DTM. The resulting point XYZ is transformed into image space using the collinearity equations of photogrammetry in the case of central projection or equivalent transformation valid e.g. for SPOT scenes. In image space a grey value is resampled from the surrounding values. This grey value is assigned to the orthoimage pixel. For coloured orthoimages one grey value per colour band is obtained. In this way the complete orthoimage is computed.

In the anchor point method, a coarse grid is constructed in object space. Subsequently, only the grid points are projected into image space using exact projection equations. The position of the remaining surface points is interpolated. In general the same accuracy can be obtained as in the pixel-for-pixel method. However, as the data structure of the DTM becomes more complex containing a combination of triangular meshes and square grid meshes, the anchor point meshes have to be chosen rather small. In the extreme case the anchor point meshes are one pixel in size, this then corresponds to the pixel-for-pixel method. Alternatives are the use of anchor point quad trees (Mayr 1993b) or a combination of the two methods (Ecker 1992).

Compared to analytical orthoprojection the digital variant has among others the following advantages:

- faster processing cycle,
- greater flexibility in the selection of the orthoimage scale,
- use of image processing tools for improving the radiometric quality,
- use of multiple images to circumvent occlusions,
- use of mosaiking for generating a seamless product,
- possibility to easily extract the topographic information in 3D from the single image combined with the DTM (digital mono plotting),
- possibility to check and improve the DTM quality using orthoimages of two overlapping original images,
- easy superimposition of vector information such as height contours,
- efficient integration in geographic information systems as backdrop information or for further processing.

Today the large amount of data, which has to be dealt with if digital imagery comes into play, still somewhat limits the application of digital orthoprojection. However, a rather large number of land survey institutions and private companies around the world start to exploit this method (Heipke 1993). This signalizes the increasing success of digital orthoprojection.

3. GENERATION OF THE COLOURED ORTHOPHOTO MAP

This chapter briefly describes the individual steps for the generation of the coloured orthophoto map Vernagtferner 1990 in the scale 1 : 10,000. A detailed report on this work is contained in M. Rentsch (1992).

3.1 INPUT DATA

As described above, input data for the orthoprojection are a digital image, the parameters of interior and exterior orientation of this image and a DTM of the area.

For the presented example a strip of analogue colour images of scale 1 : 33,000 was acquired in August 1990 using a ZEISS RMK 15/23 aerial camera. An aerotriangulation was carried out on an analytical plotter yielding the parameters of exterior orientation. Subsequently one image was scanned in three colour bands at a resolution of 30 μm each, using the Zeiss PhotoScan PS1. The resulting amount of data was about 180 Mega Bytes.

Using two overlapping analogue images of the flight strip approximately 12,000 breakline points and 37,000 grid points were measured stereoscopically by an experienced operator by means of an analytical plotter in an area of 5×6 km^2. This large amount of points was necessary to adequately represent the complex object surface. From these data we generated a DTM with 20 m mesh size and an exact representation of the geomorphological information (breaklines, single points etc.) using the DTM program package HIFI (Ebner et al. 1988).

3.2 DIGITAL ORTHOPROJECTION AND ORTHOPHOTO MAP PRODUCTION

The digital orthoprojection was carried out using the programme system DIR (digital image rectification) developed at the Chair for Photogrammetry and Remote Sensing (Mayr, Heipke 1988). The size of an orthoimage pixel followed from the required resolution of the final (analogue) orthophoto (80 l/cm = 125 μm) and the orthoimage scale (1 : 10,000) and was set to 1.25 m $\times$ 1.25 m in object space. The resulting number of orthoimage pixels was approximately 5000×4000 (20 Mega Bytes for each colour band).

Subsequently the printing master copies were produced using the Hell Scanner CTX 330

Fig. 2 a: Orthoimage window superimposed with breaklines

Fig. 2 b: Orthoimage window superimposed with contours

of the Bayerische Landesvermessungsamt Munich. Finally the coloured orthophoto was superimposed with height contours, digitally derived from the DTM and combined with usual cartographic information. The final product is enclosed in this issue of the journal. In figure 2a the measured breaklines are superimposed on the orthoimage for a window of approximately 1000×1000 pixels. The breaklines run exactly on the mountain ridges, showing the high geometric accuracy of the computed orthoimage. Figure 2 b shows the same window superimposed with the derived height contours. Again, the correspondence of the image information and the contours is clearly visible.

4. INVESTIGATIONS OF THE GEOMETRIC ACCURACY OF THE ORTHOPHOTO MAP

Different DTM lead to different orthoimages (see figure 3). Given two heights with a height difference dh for one and the same orthoimage pixel, different positions for the corresponding point in image space are the result. Therefore, different grey values are computed for the two points in image space. Let us call ds the distance between them. The value of ds not only depends on dh, but also on the absolute heights and the distance of the orthoimage pixel under consideration from the nadir point of the image. Nevertheless ds gives a good indication about the geometric accuracy of the orthoimage, if two different DTM are to be compared.

In order to demonstrate the potential of the pixel-for-pixel method the influence of two DTM with different geometric accuracy on the result was investigated.

- The first DTM had a mesh size of 50 m. The collected breaklines (see above) were not introduced into the DTM computation. The accuracy of this DTM approximately corresponds to commercially available data.
- The second DTM is the one employed for the generation of the orthophoto map, thus containing all the collected geometric information of the object surface.

Shaded perspective views of both DTM are shown in figure 4 a and 4 b. In this representation the different accuracy is clearly visible.

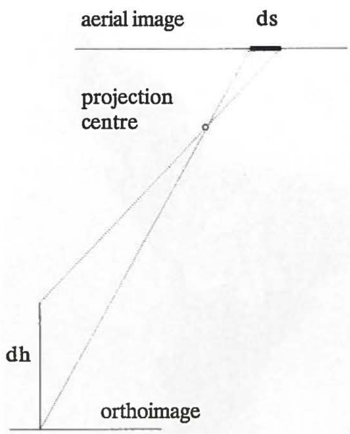

Fig. 3: Different DTM lead to different orthoimages

Subsequently, the maximum height difference dH_{max} of both DTM and its influence ds on the image coordinates in the orthoimage have been computed for the window depicted in the figures 2 a and 2 b (see table 1). It can be seen that the position of one and the same point varies considerably, in this case up to 3.45 mm or 27.6 pixels, respectively. In order to visualize these effects for the window orthoimages were computed using both DTM. The difference image is depicted in figure 5 superimposed with the measured breaklines. While grey value differences between the two images not only result from the different DTM heights but also from the

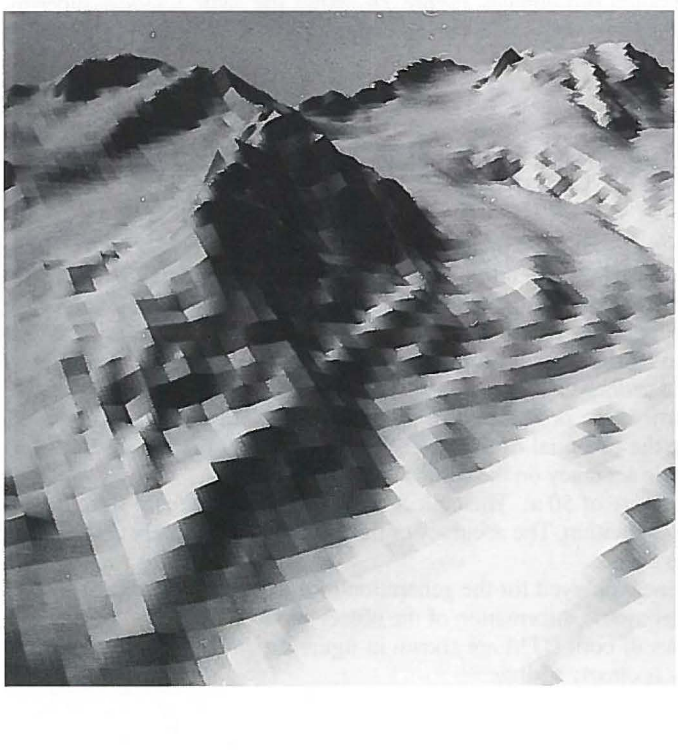

Fig. 4 a: Perspective view of 50 m DTM without breaklines

Fig. 4 b: Perspective view of 20 m DTM with breaklines

image texture, the influence of the additional geometric and geomorphologic information can be clearly seen.

Table 1: Influence of the maximum height difference dH_{max} in the aerial and the orthoimage

Comparison between	dH_{max} [m]	aerial image 1:33,000 ds [mm]	Influence on the orthoimage 1:10,000 ds [mm]	orthoimage 1:10,000 ds [pixel]
20 m DTM with breaklines and 50 m DTM without breaklines	46.3	1.0	3.45	27.6

5. CONCLUSIONS

In this project it could be shown that the position accuracy of orthoimages is substantially increased if a highly accurate DTM is used for the description of the object surface. One problem encountered is that of occlusions leading to a wrong image content in some parts of the orthophoto map. Occlusions, however, can be overcome in the digital domain, if occluded areas are determined beforehand from the DTM and the orientation parameters of the image. These areas can then be filled with information from a different image, which is generally available. Another problem encountered was that the high dynamic range of the analogue image was not reflected in the scanned version. Brightness and contrast adjustment could partly compensate for this deficiency.

Fig. 5: Orthoimage window, difference image

Despite of these problems digital orthoprojection will develop into a standard procedure of digital photogrammetry yielding high quality and inexpensive products. A further example is depicted in figure 6. It contains a perspective view of the DTM superimposed with the orthoimage and gives a rather realistic impression of the whole area.

Fig. 6: Perspective view, orthoimage and DTM

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