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High quality rectification and image enhancement techniques for digital orthophoto production

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ABSTRACT

A method for digital orthophoto production, that uses a digital terrain model (DTM) comprising both raster and vector data will be presented. This method overcomes the problems of relief displacement in large scale maps caused by the insufficient accuracy of a simple raster DTM. Image enhancement techniques particularly adapted for orthophoto production show another advantage of the digital orthophoto technique. The presented methods have been applied to an orthophoto project of 145 maps in western Austria.

1. INTRODUCTION

The development of geographic information systems (GIS) managing hybrid data sets has created an increasing demand for digital orthophotos. In this paper some aspects on digital orthophoto generation, underlining the advantages of this method compared to the conventional analogue technique (Otepka, Loitsch, 1976), will be discussed. The methods presented have been realized for an orthophoto project of the Lechtal area in western Austria.

Figure 1 shows the context of different steps necessary for generating a digital orthophoto. If the input image is a photographic film, it must be digitized by using an appropriate scanning device, which converts the continuous greytones into a matrix of picture elements (pixels).

Preprocessing of the digitized data might be useful or even compulsory for image restoration, image enhancement, and geometric and radiometric calibration due to the properties of the scanning device. High quality scanners use their own calibration values and deliver already corrected results. These resulting image data are input values for further processing.

Firstly the parameters for the perspective transformation of the 3D-object-space (terrain surface) into the 2D-image-space have to be evaluated through a photogrammetric orientation process. Prerequisites are coordinates of control points known in object space and in image space. The image coordinates of the control points may be measured by using a photogrammetric comparator providing coordinates in a planimetric x,y-system defined by the axes of the comparator. As pixel data are already available the measurement of the (sub-)pixel positions within the image matrix is to be prefered. The computer can be used instead of expensive and precise mechanical instruments for coordinate measurement.

The parameters of the exterior orientation of the images must be calculated through a bundle adjustment program or a simplier orientation procedure by using image and terrain coordinates of the control points mentioned above.

The creation of a DTM can be subdivided into two tasks: The acquisition of the terrain data and the interpolation of the DTM. The geometric quality of the resulting orthophoto mainly depends on the accuracy of the input data captured during data acquisition. The latter becomes one of the crucial parts of the whole process and special attention must be paid to it.

The following geometric rectification is the most time-consuming task, comprising the reconstruction of the geometric properties of the relationship between real terrain, image data and map projection (defined by the orientation parameters and the DTM data base), and the resampling of the pixels of the digital images data into the rectified digital photo. Commonly image enhancement procedures are applied to the rectified image during a postprocessing step using contrast stretching, filtering and other techniques of the vast field of image processing. Further digital

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orthophotos may be joined together forming an uniform image mosaic. For the generation of an orthophoto map further cartographic work has to be done, such as lettering, annotation,framing etc.

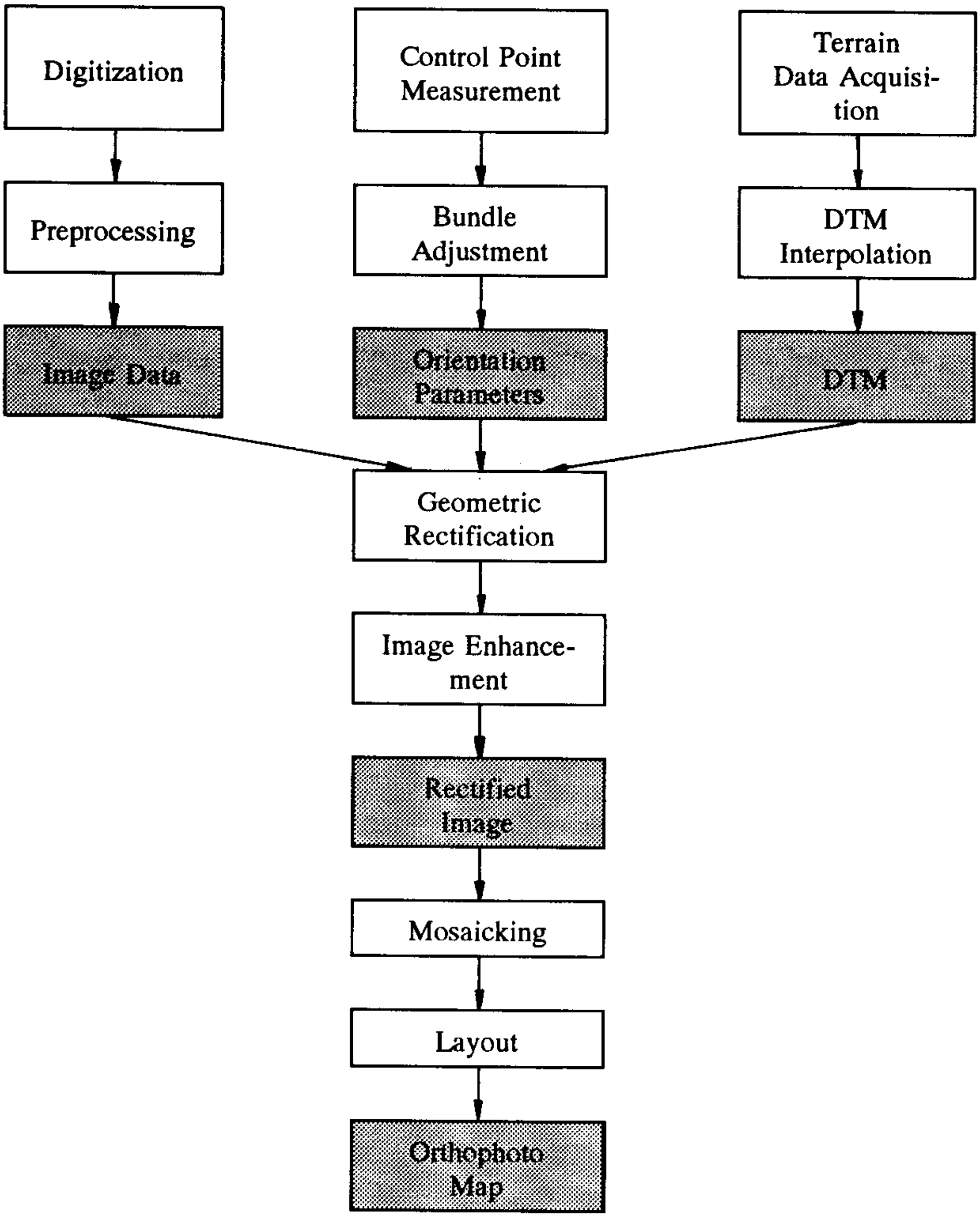

Figure 1: Generation of orthophoto maps.

2. TECHNICAL ASPECTS ON ORTHOPHOTO GENERATION

This chapter focuses on three aspects of orthophoto generation:

- DTM
- Geometric rectification
- Image enhancement.

Eventually the advantages of digital orthophotos compared to analogue orthophoto should be emphasized.

2.1 High quality DTM

A digital terrain model represents the shape of the terrain surface. The DTM defines the terrain elevation for any planimetric position. DTMs may be built up in various ways, most commonly they are organized as regular raster DTMs based on a constant grid width. These simple and often rather coarse DTMs can hardly model discontinuities of the terrain surface, such as breaklines, bridges, ridges etc. which might cause considerable local displacements of image details, so deteriorating the geometric quality of an orthophoto. One solution to improve the quality of the DTM without increasing the amount of data significantly is interlacing the raster data with vector data. For large scale rectification such a sophisticated DTM structure is a precondition. The SCOP-DTM (Köstli, Sigle, 1986) meets these requirements and was the foundation for all rectifications mentioned later in this article.

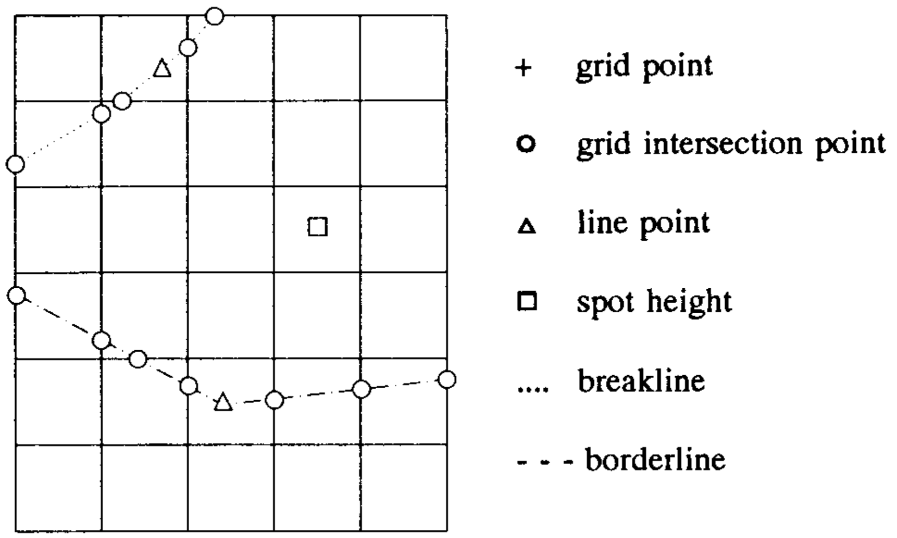

Figure 2: Data structure of the DTM.

Figure 2 allows a closer look into the internal organization, showing a window of a SCOP-DTM. It contains 42 grid points, one breakline, one borderline and one spot height. Other points in this graph are grid intersection points, which are not members of the originally captured set of vector data. They are generated during the building-up process of the DTM and are located where the regular grid lines intersect the linear vector elements. A breakline, for example, consists of line points and grid intersection points. For quick access, grid and line points are connected by pointers.

2.2 Geometric rectification

The process of mapping the preprocessed but still distorted image to the orthophoto image is called geometric recitification. The rectified image has the geometric properties of the map plane. The orientation parameters of the image, the DTM and the digital image data are the input. The relation between the regular grid in the map plane (X-Y-plane) and the corresponding distorted grid in the photo (x-y-plane) is based on the central perspective projection from the 3D-terrain-surface into the 2D-image-plane (see figure 3). This relationship can be expressed mathematically through the well-known collinearity equations (Kraus, 1993).

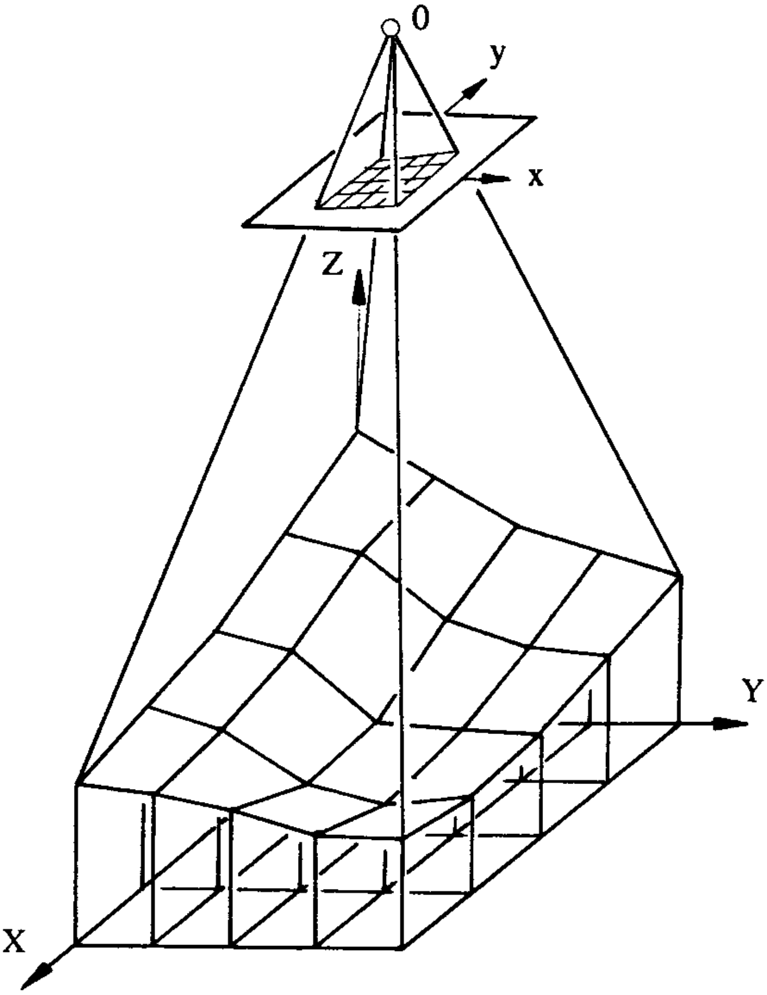

Figure 3: Relationship between a regular grid in the map and on the photo.

Conventional digital as well as analogue orthophoto techniques sequentially transform each point of the distorted grid mesh on the image plane into a corresponding rectified point of a square mesh of the map plane by applying the collinearity equations. The image contents within a mesh is transformed by using bilinear interpolation, which is only a more or less good approximation of the correct perspective transformation. The corner points of the mesh serve as so called anchor-points (Bähr, 1989 and Wiesel, 1991), which are the only points transformed in the theoretically correct way. They are used for the determination of the parameters of the bilinear interpolation. Usually the mesh width of the rectified grid is much greater than the pixel size of the orthophoto. Then pixels within a mesh are rectified by bilinear interpolation.

In order to take into consideration the additional vector information without making the whole process too complicated the program distinguishes between meshes without and meshes with further information. Pure grid meshes will be transformed in the conventional way. The pixels of meshes containing additional vector data or spot heights are transformed separately by applying the collinearity equations pixel by pixel. Although the pixel by pixel method could be used for all meshes, independently of whether they contain additional information or not, it would just tremendously increase the computing time without improving the geometric quality.

Figure 4 demonstrates the advantage of the proposed method. The upper image shows the breaklines of the DTM on the left hand side, and the resulting orthophoto on the right hand side.

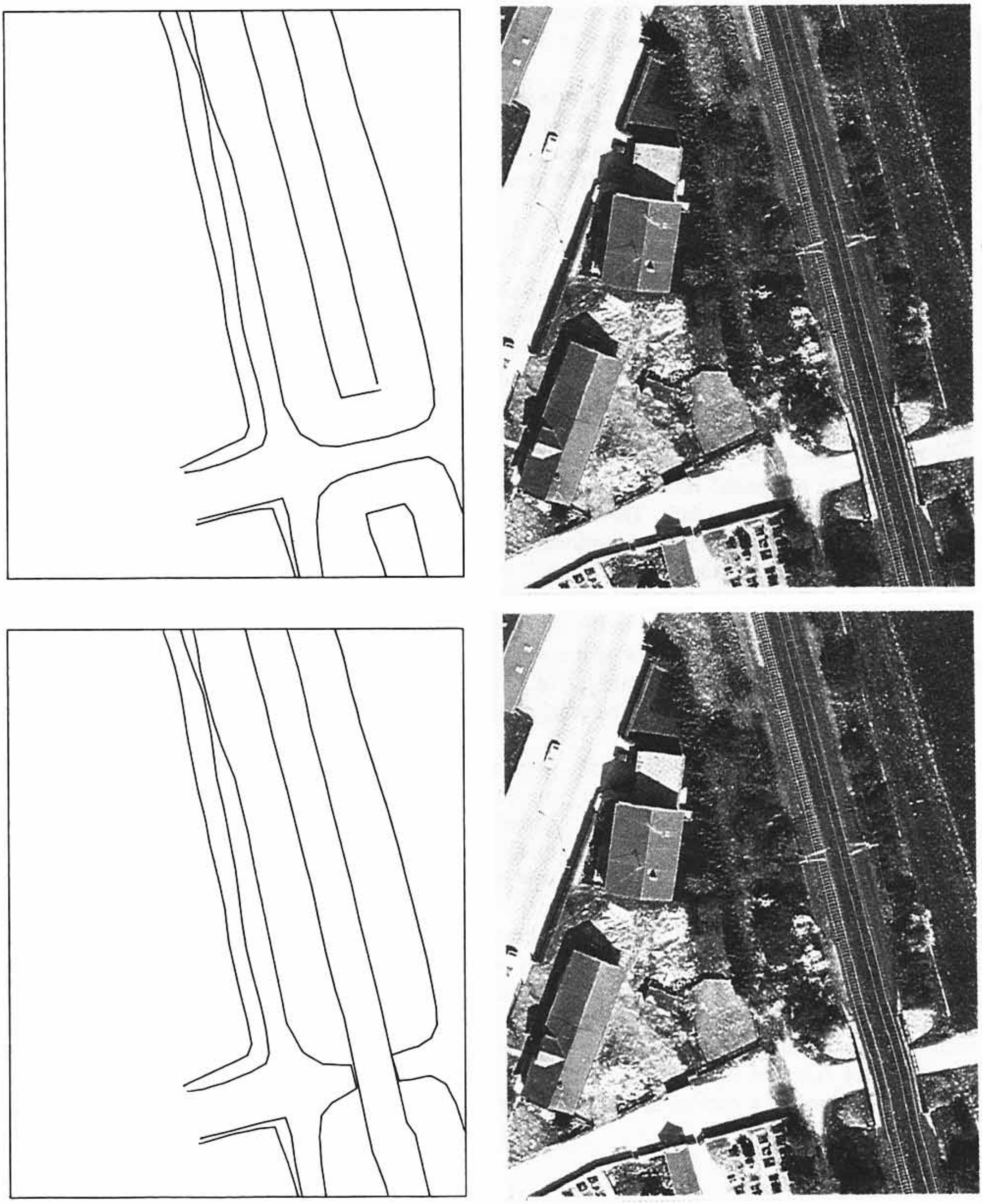

Figure 4: The influence of breaklines on orthophotos.

Since data acquisition concentrated on the terrain surface only, the bridge is still distorted in the orthophoto. A simple raster DTM of equal grid width would even cause additional distortions. The lower picture in figure 4 shows the correctly mapped bridge. This result could be achieved by adding breakline data along the bridge as one can see in the breakline plot on the lower left hand side.

This example should emphasize the importance of additional vector information stored in the DTM data set. The larger the scale of the orthophoto, the greater the influence of objects located on the top of the terrain surface on the geometric quality, and the greater is the demand for high quality DTM information and sophisticated DTM structure.

2.3 Image enhancement techniques

One advantage of digital orthophoto-generation is the option of image-processing, which is more capable and better controlled than conventional reprographic methods. The goal of image-enhancement is an optimum representation of the data, especially regarding the application for which the product is dedicated. Thus, one will expand the contrast within the brightness-region containing the main objects of interest, what will lead to more details within this specific range of greyvalues. On the other hand, for all other regions the dynamic range is diminished and details will be less detectable. With the given project, the banks of the Lech river - with very bright intensities - are of special interest, but also the surroundings should appear well. Some of those areas, e.g. wood, are very dark. Therefore, a good reproduction of details in bright as well as in dark areas is not possible with conventional methods of contrast-manipulation.

It is possible to discriminate between "global" contrast, as it is represented by the histogram of the whole image and derived statistical parameters, and "local" contrast, which is the difference in brightness of one pixel compared to the average within its close neighborhood. Global contrast is influencing the general appearance of the image, while the representation of the details is due to local contrast. By independent treatment of both contrast-components, we can flatten the global dynamic range, so that in addition the local contrast may be enhanced in all parts of the image:

$$X = F_1[m+(sgn(x-m)*F_2[x-m])]$$

- x greyvalue of original pixel
- m medium greyvalue within 5x5-neighborhood
- F_1 global contrast-function
- F_2 local contrast-function
- X new greyvalue

The contrast-functions F_1 and F_2 are determined as lookup-tables, valid for a set of images of similar properties (as it is with images within one strip and equal scanning-parameters), based on histogram-analysis. For a good general appearance of the whole image, F_1 is performing a histogram-equalization adapted to Gaussian distribution (with $\sigma=\pm60$). This is producing an image with a certain dominance of medium greyvalues, but darker and brighter pixel occurring as well. The effect of function F_1 from Fig.5b can be seen in Fig.5a (concerning the histogram) and in Fig.6a-6b (applied to a portion of original scanner-data).

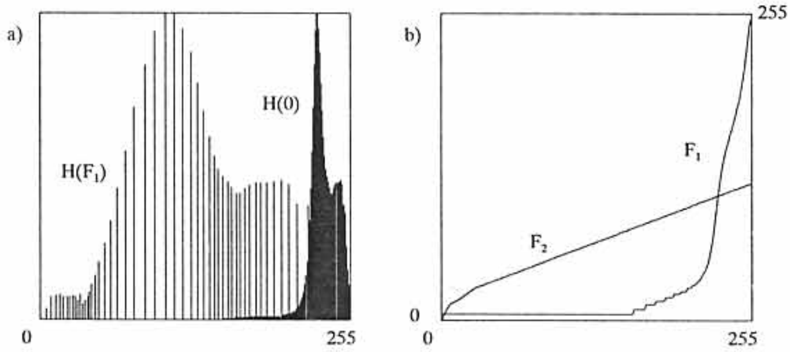

Figure 5a: Histogram H(0) of image Fig. 6a and histogram $H(F_1)$ of Fig. 6b (after applying F_1).
Figure 5b: Contrast-functions F_1 and F_2, responsible for global and local contrast-enhancement.

a) b) c) d)

Figure 6a: Portion of original scanner-data in positive representation (histogram see Fig.5a).
Figure 6b: Result of contrast-function F_1 of Fig.5b applied to Fig.6a (histogram see Fig.5a).
Figure 6c: Detail of Fig.6b at full resolution (512 by 512 pixel), local contrast not enhanced.
Figure 6d: Result of enhancement applied to original data (with functions F_1 and F_2 of Fig.5b).

The improvement applying local contrast-enhancement is demonstrated in Fig.6c and Fig.6d. Compared to a linear convolution, as it is the well-known Laplacian filter-kernel, in many cases the results of the presented method are smoother - but without loosing details. This is due to the changing behavior of the local contrast-function, depending on the actual difference between the given pixel and the medium of its neighborhood. Because very small differences are less amplified, an affection by noise often can be avoided. But also large local differences are less enhanced, so that exaggerating effects (which may occur at distinct edges using linear filters) are suppressed.
The main benefit of image-enhancement based on global and local contrast-manipulation is that, while the general appearance of an image may be kept, the details are intensified at all greyvalue--levels. By automatic derivation or manual selection of arbitrary types of global and local contrast-function, various processes and effects easily can be applied to an image. Therefore, this technique also is a useful tool for many tasks and applications of image-processing.

3. PRODUCTION OF ORTHOPHOTO MAPS OF THE LECHTAL PROJECT

The Ingenieurgemeinschaft Vermessung AVT, a group of surveying engineers, was commissioned by the Planning Department of the District Council Reutte of Tyrolean State Government (Amt der Tiroler Landesregierung, Bezirksbauamt Reutte) to photogrammetric and surveying works within the project. The area of interest was the valley of the Tyrolean part of the river Lech (Lechtal) extending about 60 km in length. Up-to-date orthophoto maps at the scale 1:1000 were required by the Planning Department for planning and administration tasks as well as for diverse hydrological investigations within the scope of the regional study "Lech".
The reasons for the decision of producing digital orthophotos rather than analogue ones were:

- The usual demand for "One-Image-One-Orthophoto" can hardly be fulfilled for the narrow valleys in the mountainous area. The possibility of digital mosaicking is a convenient way for solving the problem.
- The bright gravel of river banks next to dark wooded areas causes photographic problems resulting in photos of high global but low local contrast, thus reducing important image information. In order to obtain good radiometric quality extensive photographic processing would be necessary. Digital image processing techniques can handle this problem efficiently.
- For future applications a digital data set should be provided, which can be integrated into the Tyrolean Geographic Information System TIRIS (Otepka, Wiggering, 1991). Digital orthophotos can easily be imported into GIS data sets.

3.1 Aerotriangulation and DTM generation

For various reasons the photo flight had to be carried out at low water level of the river Lech and before the shooting of the leaves. Due to the topography of the terrain the photo flight had to be divided in two parts. The photos of the northern lower part of the valley were taken in the third week of March. Those of the mountainous southern part had to be taken three weeks later because of snow coverage.
Altogether 20 strips comprising 414 black and white photos were necessary for covering the area of interest. The image scale was about 1:4000, the overlap more than 80% and the side lap more than 25%. A Zeiss aerial camera with a focal length of 210 mm was used. The control points for aerotriangulation were targeted points as well as natural details.
The data acquisition for the DTM was done through static grid measurement by selecting a regular grid width of 20 m and through digitization of breaklines. All measurements were performed on a Zeiss Planicomp analytical stereoplotter. The program package SCOP (Molnar, Waldhäusl, 1993)

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was used for the interpolation of the DTM and for the computation of the contour lines. Although a contour line interval of 0.5 m was requested for the lower part of the valley, it had to be increased to 2 m for the steep areas. SCOP can adapt the interval automatically according to the slope of the terrain.

3.2 Digitization of the aerial images

105 black and white images were digitized with the photoscanner PS1 of Zeiss-Intergraph (Faust, 1989). A pixel size of 30 μm was chosen. This size can be regarded as appropriate for good image quality and a reasonable amount of data. The radiometric range of the PS1 is predefined with 256 grey values. Images within the same flight strip were scanned using the same radiometric settings of the scanner, as this guarantees little grey differences along the joints of the rectified mosaic.
The PS1 enables the definition of the scanning range and direction nearly independently from the position of the image on the photocarriage. Therefore the approximate pixel coordinates of the fiducial marks are always the same. This proved to be a valuable feature for automatic measurements of fiducial marks by matching (Rottensteiner, 1993).

3.3 Rectification, image enhancement, mosaicking

The input data for the rectification, such as digital image data, orientation parameters and the DTM data were provided by the AVT company. The rectification was performed by the Institute of Photogrammetry and Remote Sensing (I.P.R.) at the University of Technology in Vienna applying a prototype orthophoto modul of SCOP.
The first task is the measurement of the fiducial marks within the digital image matrix, in order to get the relation to the orientation parameters. This measurement was performed manually (in most cases) as well as automatically. The automatic procedure was part of a research work and was applied here for the first time. The difference between manual and automatic measurements was about 1/4 of a pixel (Rottensteiner, 1993).
The rectification was performed in batch mode on an HP 9000/730 Unix workstation. Bicubic resampling was chosen for avoiding aliasing and deterioration of the radiometric quality. The breakline information was taken into consideration in order to achieve the utmost quality of the orthophotos.The computing time for one picture was about 35 minutes. After a visual check on the workstation screen the cutting lines for digital mosaicking were selected manually and the parameters for the global contrast function (see 2.3) could be estimated. Image enhancement took about 17 minutes per image. If necessary the mosaicking procedure was started afterwards.

3.4 Image output and map layout

Hardcopy plots of the digital image were exposed on the laser rasterplotter LRP 25 of Leica (Ecker, Jansa 1989), a transputer based photoplotter with electronical screening capability for the generation of continous tone images only. Therefore the integration of vector data (frame, contours, axes of the river, cross sections, etc.) into the map had to be done in conventional photographic manner. Figure 7 at the end of the paper shows one map. From digital orthophotos in concert with a DTM further products such as perspective views can be compiled (Ecker, 1991 and Kuhn, 1989). Figure 8 shows a view on the upper course of the Lech.

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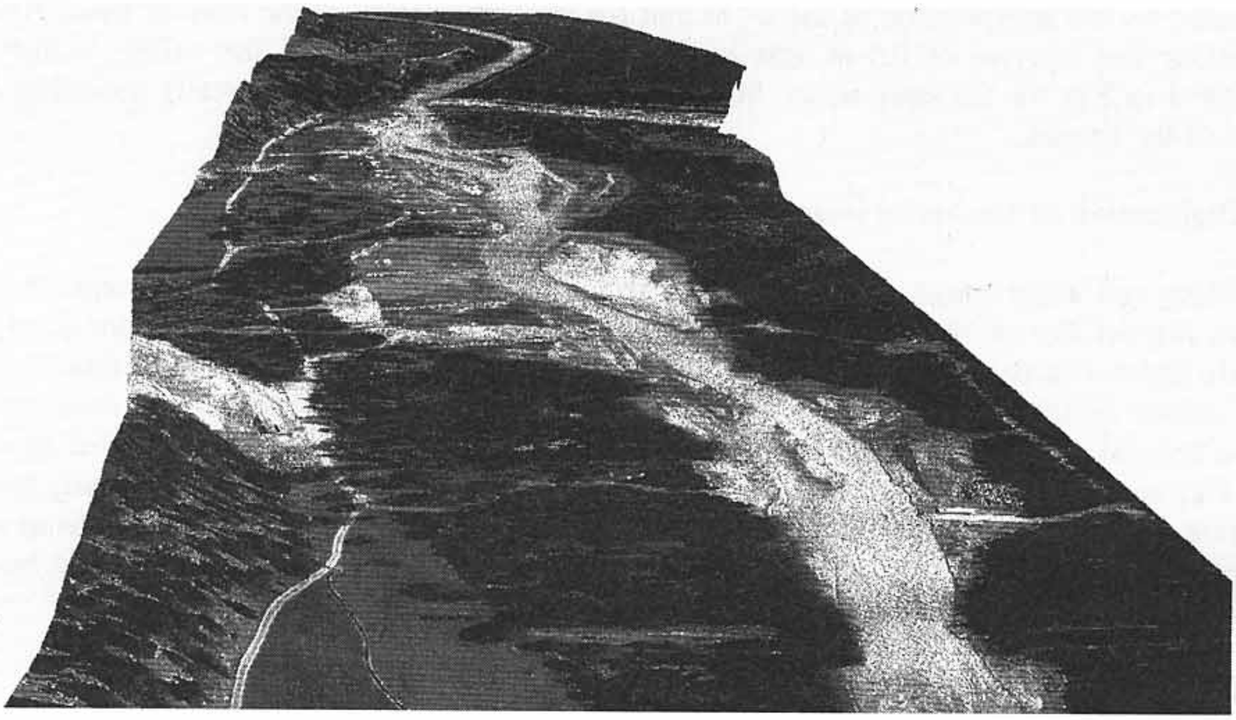

Figure 8: Perspective view of the upper Lech valley.

3.5 Technical and organizational aspects

In dark forest areas black contour lines could sometimes hardly be recognized. Different solutions for this problem can be proposed.

- Increasing grey values in dark areas through a contrast function
- Rasterization of contour lines with grey values that contrast to the background.
- Masking out contour lines

Since orthophotos were produced first and contours later only the first method could be used. For experiment purposes the third method was tested. In the orthophoto narrow bands defining the contours were masked out. A vector overlay containing the contour lines could be displayed together with the orthophoto. The visibility of the contours was excellent, but due to the thickness of the bands the image contents was destroyed considerably.
The hardware used for rectification was:

- 1 HP 9000/730 workstation with 64MB memory
- 2 Hardiscs each 1.3 GB
- 1 Exabyte tape drive
- 1 High resolution graphics terminal (1280 * 1024 Pixel)

The following statements are based on the experiences from the Lechtal project.

Process	Result	Required disc space	Computation time
Data import	Raw data	59 MB (7680*7680)	4 minutes
Data conversion	Image data	59 MB	3 minutes
Rectification	Rectified image	ca. 35 MB	35 minutes
Image enhancement	Enhanced orthophoto	ca. 35 MB	17 minutes
Mosaicking	Mosaic	ca. 25 MB	3 minutes

Table 1: Required disk space and computation time for orthophoto generation.

Table 1 shows the result of different processes, the required disk space and processing time for one image. In order to economize disc space it can be recommended to delete the results of a previous step. Thus, the minimum available disc space for the generation of one orthophoto can be reduced from 213 MB to 118 MB.
If the pixel coordinates of the fiducial marks could be matched automatically, data import, data conversion and rectification can be performed in one batch process. At this stage of orthophoto production interaction is necessary to define the joints of the mosaic and to compute the global contrast function for one strip. Image enhancement and mosaicking may be computed in background or in a batch process.
For an efficient orthophoto production it is advisable to organize work in the manner that the computation intensive rectification is performed during the night. The following work flow can be proposed. Just before work closes a job for data import, data conversion and rectification can be started. On the next day the results can be checked. Image enhancement, mosaicking and backup will complete the work. The bottle-neck of this workflow is not computation time, but disk space and operating of the tapes.
For the presented project a turn around time between 2 and 3 hours for one image could be achieved.

4. CONCLUSIONS

The advantage of digital orthophotography compared to the conventional analogue technique is obvious. Methods of digital image processing can be applied, thus providing the possibility for improving the radiometric quality of the images. But also the geometric quality of the orthophotos can be increased, if only the DTM data base can handle information of terrain discontinuities. An adaptive procedure, choosing a pixel by pixel or mesh based simplified rectification, minimizes the computational effort while maximizing the geometric accuracy. Finally mosaicking can be done in a much more efficient and convenient way. Compared to the analogue technique production time will be about the same in the near future.
The examples explained in the sections above should prove that this method is not an academic and theoretical solution, but can already be used for orthophoto production. Though there are no extraordinary hardware requirements, it must be mentioned that limited disk space can be a bottle-neck. Besides this, we should not forget one of the main advantages: digital orthophotos are computer generated and thus computer compatible geocoded data sets which may be imported into

GIS. The combination of various GIS information and image information will become increasingly important for planning purposes, interpretation, administration and documentation.

5. REFERENCES

Bähr, H.-P. (1989): Das digitale Orthophoto und seine Möglichkeiten. Proceed. 42. Photogrammetric Week, pp. 243-260, Stuttgart.

Ecker, R., Jansa J. (1989): Digital Terrain Models and Digital Image Processing. In: Geo-Informationssysteme - Anwendungen - Neue Entwicklungen, pp. 343-350, Wichmann, Karlsruhe.

Ecker, R. (1991): Rastergraphische Visualisierungen mittels digitaler Geländemodelle. Geowissenschaftliche Mitteilungen, Heft 38, Wien.

Ecker, R. (1992): Digital orthophoto generation based on a high-quality DTM. ITC Journal 1992-1, pp, 59 - 64.

Faust, H. (1989): Digitalisierung photogrammetrischer Bilder. Proceed. 42. Photogrammetric Week, pp. 69 - 78, Stuttgart.

Köstli, A., Sigle, M.(1986): The random access data structure of the DTM program SCOP. ISPRS Symposium, Commission 4, Volume 26, pp.45 - 52, Edinburgh.

Kraus, K. (1993): Photogrammetry - Volume 1: Fundamentals and standard processes. Dümmler, Bonn.

Kuhn, H. (1989): Digitale Erzeugung von Perspektivbildern. Deutsche geodätische Kommission, Reihe C, Heft 347, München.

Molnar, L., Waldhäusl, P. (1993): Produktinformation SCOP, Wien.

Otepka, G., Loitsch, J. (1976): A computer program for digitally controlled production of orthophotos. ISPRS Symposium, Commission 4, Volume 21/6, pp. 202 - 204, Helsinki.

Otepka, G. Wiggering, J. (1991): Die Einbindung des digitalen Orthophotos in ein Geoinformationssystem. In: Geo-Informatik: Anwendungen, Erfahrungen, Tendenzen. pp. 95 - 106, Siemens Nixdorf Informationssysteme AG, München.

Rottensteiner, F. (1993): Flächenbasierte Korrelation von Rahmenmarken in abgetasteten Bildern. Diploma thesis at the University of Technology, Vienna.

Wiesel, J. (1991): Digitale Orthophototechnik. In: Digitale Bildverarbeitung - Anwendung in Photogrammetrie und Fernerkundung, pp. 137 - 144, Karlsruhe.

Figure 7: Orthophoto map.