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Production of Digital Orthophotos and Orthophotomaps at the Bavarian Land Survey Office

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ABSTRACT

After 17 years of practical experience in production and application of analog orthophotos using analytical differential rectification, the BLVA started the operational use of digital orthophotography in 1996. The main application up to now is the derivation of orthophotomaps statewide, done completely through digital image processing. The production steps are explained and an outlook is given at the orthophoto database which is under construction.

1. INTRODUCTION

In 1979 at the „*Bayerisches Landesvermessungsamt*“ (BLVA; i.e. *Bavarian Land Survey Office*) the production of *orthophotos* started soon after an analytical orthoprojector *Wild* Avioplan OR1 had been acquired in 1978. In the beginning, orthophotos in the scale of 1:10000 from aerial images of scale 1:23000 were made mainly for internal use, i.e. for the revision of the *topographical map series 1:25000*.
In 1983 – in addition to this first application – the production of *analog orthophotomaps* has been started on the basis of orthophotos 1:5000 (and 1:10000). These mapsheets have been widely used since then by state and city authorities, e.g. for planning purposes (forestry, roads, water, housing), environmental studies. In order to be able to make these orthophotomaps within a reasonable timespan, data for a *statewide digital terrain model* (grid-spacing 50 m) were collected and processed from 1985 until 1992 (Reiss, 1990; 1996).
Beginning in 1995 a new program was introduced for a *systematical production of orthophotomaps*. This happened at the same time when a change in technology took place, caused by the acquisition of new equipment for the production of digital orthophotos (Reiss, 1996; Kerner, 1997).

2. PRODUCTION CONCEPT

The output of analog orthophotos 1:10000 for map revision was organized rather systematically, right from the beginning of the operational use of analytical orthophotography. The sole purpose of updating map layers did not demand for sophisticated cartographic additions.
When the production of orthophotomaps – based upon orthophotos of scale 1:5000 and 1:10000 – was introduced in 1983, these new products were offered on demand only. Consequently the first customer had to pay a rather high percentage of the production costs. This procedure remained effective during the first 12 years of production (1983-1994). Then in 1994 a working group consisting of members of the Bavarian Ministry of Finances and the BLVA developed a new concept:
Within a 10-year period (beginning in 1995) *orthophotomaps* will be produced statewide, fitting in scale and size the *cadastral map 1:5000* (FK 5). Since the cadastral map mainly shows property boundaries and buildings, the idea was to supplement these maps regarding topography through the overlay of orthophotos. The basic orthophotomaps can be delivered as is (only a minimum of texts and four corner marks added) or in combination with additional layers such as cadastre, contours, etc.

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3. PREREQUISITES

In order to produce orthophotomaps – in addition to suitable *aerial images* – there are *control points* and a *digital terrain model* necessary as well.

3.1 Image Flights

Each year 2 large-area flights cover approx. 1/5 of the state of Bavaria each. Thus within a 5-year cycle the whole area of the state is covered by aerial images of two different scales using b&w film. These flights are organized in such a way, that for most parts of the state there are up-to-date images available not older than 2-3 years.

- The „*Topographische Befliegung*“ (i.e. *topographical flight*) is carried out since the late seventies using an image scale of 1:23000. It is designed to cover one sheet of the topographical map 1:25000 (TK 25) with 3 x 3 images (or orthophotos resp.). The area covered every year considers the boundaries of the 1:50000 map sheet series (TK 50); areas and years of flight are coordinated between neighboring states of the Federal Republic of Germany. Its primary purpose is the production of orthophotos/orthophotomaps 1:10000 to be used for map revision.
- The „*Bayernbefliegung*“ (i.e. *Bavaria-Flight*) is oriented towards map production for the orthophotomaps in 1:5000 using an image scale of 1:15000 (Frankenberger, 1988). It started for a 3-year period first and is organized in a 5-year cycle since 1990. The area covered every year contains complete planning regions (as far as possible) and the area of one sheet of the cadastral map (FK 5) is covered by one single aerial image/orthophoto.

3.2 Control Points, Orientation

From 1995 on, systematic field measurements using GPS-equipment are carried out to supply a frame of *terrestrial control points* for densification by *aerotriangulation.* The initial planning intended to measure and archive a rather dense network of control points to provide sufficient points in every image for absolute orientation. Since *digital aerotriangulation* made an enormous progress during the last few years, the whole philosophy has changed in the meantime. *Automatic aerotriangulation* in connection with *bundle block adjustment*, supported by *camera positioning* using *kinematic in-flight DGPS*, gives the parameters of absolute orientation for every single image without the need of many interactive measurements. This is one more step towards the automation of the orthophoto production process and is applied at the BLVA for some of the image blocks, currently still in a pre-operational stage.

3.3 Digital Terrain Model

In order to correct distortions caused by terrain elevations, a *digital terrain model* (DTM) is necessary. In the beginning DTM data were collected during the production process from the same imagery, that was used for differential rectification. Then between 1985 and 1992 a systematical DTM data collection and archival was done, mainly using photogrammetric profiling at analytical or analog stereoplotters (image scale 1:23000). This was done to a large extent by private companies. For the higher mountainous area in the Alpes contours (mapping scale 1:10000) were available (from analog stereocompilation; image scale 1:23000), that were manually digitized (completely by private contractors). From these primary data a *statewide DTM* was derived and stored as a large Z-matrix, that is readily available in 50 m-, 100 m- and 200 m-gridspacing.

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4. PRODUCTION STEPS

4.1 Historical Development

As mentioned before, until the end of 1994 orthophotos were made at an analytical orthoprojector. To refine this into a orthophotomap, separate layers (containing orthophoto, frame, grid-crosses, texts and optional overlays, e.g. contours) had to be mounted manually. Therefore, orthophotomaps were produced on demand only. After a series of tests during 1993/94 a digital photogrammetric system *Zeiss* PHODIS – consisting of scanner, photogrammetric workstation and software – was ordered and finally delivered in Oct.'94. A large-format laserplotter was already at hand, that up to then had been used more or less exclusively for the output of cadastral maps.
The start of the new concept for the systematical and statewide production of orthophotomaps and the operational use of digital rectification became effective at the same time in the beginning of 1995. Thus the BLVA was able to produce the orthophotomaps designed with a new layout, aiming at full coverage of Bavaria, in a fully digital way right from the beginning.

4.2 Scanning

The first step of digital image processing consists of an *A/D-conversion* of the b&w-images 1:15000 recorded on photographic film. This is done at the photogrammetric precision scanner *Zeiss/Intergraph* PS1. It provides a radiometric resolution of 256 greyvalues and allows for geometric resolutions of 7.5, 15, 22.5, 30, 60 or 120 µm respectively. For the derivation of digital orthophotos 1:5000 and the final output in the form of analog orthophotomaps recorded on film, a pixelsize of 30 µm for scanning was found to be sufficient. The resulting size of the image files is approx. 67 Mbyte per b&w-image (currently color images are not used).

4.3 Image Processing

After scanning, the image files in the *Zeiss* TLD-format are transferred to a photogrammetric workstation (*Silicon Graphics*-computer and software *Zeiss* PHODIS). Parameters such as *scale*, *pixelsize* and *type of map* have to be defined for every new project. Then, after interior orientation, the absolute orientation is done, either interactively from existing control points or – as far as available – using orientation data from photogrammetric block adjustment.
Corner coordinates in the groundsystem for every mapsheet are available from file and can be provided programmatically. These are necessary for *area definition* (including overlap) of the digital orthophoto (DOP) and for cutting out the local DTM from the large grid file. The pixelsize used for the orthophoto is 80 µm (317.5 dpi) which gives a plotting resolution of approx. 120 L/cm and results in a ground resolution of 0.40 m (regarding map scale 1:5000). That means, that adjacent DOPs can be combined very easily to mosaics as long as the area boundaries are rounded up to values of multiples of 2 m.
All necessary input parameters, filenames and filepaths are recorded in a control file using a macro procedure. *Differential rectification* (PHODIS-OP) usually is computed in *batch mode* as a background process, mostly during the night. The resulting orthophoto-files in the TLD-format subsequently are converted to the PostScript-format (PS) and clipped according to the boundaries of the individual mapsheet.
For the final setup of a *digital orthophotomap* several *graphical elements* and *texts* have to be added to the orthophoto file such as title, sheet name, parameters of the image flight and the individual image(s) used, copyright, cornermarks, numbering scheme of neighboring sheets etc. (see Figure 1). In the standard case these binary graphics are prepared programmatically in PS-format and merged to the image file during the batch processing mentioned above.

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The post-processing software was developed in-house. Interactive editing (including the construction of map frame, texts, etc.) is done for special editions only (different scale, non-standard size, etc.) using the PHODIS-M-module including the PHOCUS-functionality. If requested, binary raster-data such as a scanned cadastral map or contour layer can be overlaid and merged to the map file (see Figure 2 and Figure 3). Standard mapsheets are derived from a single photo normally, but, if necessary, mosaics can be computed as well including the radiometric adjustment within overlapping areas (see Figure 4). Of course, this has to be prepared interactively also.

4.4 Plotting

The final *plotting* of the orthophotomaps (*D/A-conversion*) in the beginning was done at a laserplotter *Linotype-Hell* Linotronic 930. This one is not used anymore except for large formats. During 1996 a second printer was acquired (*Linotype-Hell* Hercules Pro) which works faster and supports higher resolutions including frequency-modulated rasterization. The standard resolution applied is 60 L/cm (i.e. 166.7 µm or 152.4 dpi approx.).
The resulting product after the plotting process is a *raster film* (positive or negative; usually a mirrored image) which can be reproduced either on photographic paper or as a blueprint.

4.5 Archive

The *digital orthophotos* (DOPs) derived through differential rectification are not only a necessary ingredient for the production of orthophotomaps, but are a very valuable and useful product of their own. They can be used as a separate layer to be overlaid with vector data within a *Geographic Information System (GIS),* that is able to process hybrid data sets. This can be very helpful for interpretation but also for verification, improvement of geometry and updating.
Therefore a decision was made that the DOP-files representing the refined product should be permanently stored in any case. If necessary, the scanning of the original images can be repeated easily as long as the scanning parameters are still known (quite often variations in resolution and/or radiometric parameters are necessary, anyway). Similarly the compilation of a new orthophotomap can be repeated rather easily using the same or a different layout, if the digital orthophoto can be located and loaded from a back-up medium rather quickly. Hence digital orthophotomaps are regarded as an intermediate product only, that is deleted immediately after the recording process; only the input parameters used for batch control are saved. In addition – to save storage space – the analog output of orthophotomaps on film is done only after an specific order has been placed.
In the beginning DOPs were backed up on tape cassettes (digital audio tapes, DAT), but very soon the need for a powerful *archival-and-retrieval-system* was recognized. Therefore during 1995 the planning and layout was initiated under the acronym *ILIAS („**I**nteraktives **L**uftbild-**I**nformations- und **A**uskunfts-**S**ystem", i.e. „Interactive Information- and Query-System for Aerial Imagery")* for a database to be set up on the central server (DEC) using ORACLE as the DBM-system. Since the beginning of 1997 DOP-files are saved on recordable CDs to be stored in a CD-jukebox. In addition quicklooks (ground resolution approx. 5 m) of all orthophotos are computed and saved, as soon the rectification process is finished.
The final information system will permit users to query for coverage and parameters of image flights, available aerial photographs, DOPs and orthophotomaps produced/available, including their relations to each other and to the different map series as well as to geographical objects (communities, traffic and water network, municipal boundaries, etc.). Therefore all existing information on image flights, individual images, orthophotomaps, etc., will be integrated. Later on, other data, such as *ATKIS*-vector data and/or *cartographic raster data* (Zahn, 1993) could be added as well.

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5. PRODUCTS, MARKETING

5.1 Digital Orthophotos

In the last two years since digital orthophoto products were offered, there was a rather small number of requests for raster data; but, definitely, there will be a growing demand for DOPs, when the necessary know-how and more suitable equipment will be at hand for potential users. Internal use for DOPs will be for map revision and update of the official German national GIS called *ATKIS („**A**mtliches **T**opographisch-**K**artographisches **I**nformations-**S**ystem“).*

5.2 Analog Orthophotomaps

Orthophotomaps 1:5000 fitting the official *cadastral map* (FK 5) in scale and size are produced out of DOPs in different editions:

- Orthophotomap 1:5000, standard edition (LK 5, see Figure 1),
- Orthophotomap 1:5000, including cadastral overlay (LK 5 F, see Figure 2),
- Orthophotomap 1:5000, including contour overlay (LK 5 H, see Figure 3) – as far as appropriate contours are available – and
- Orthophotomap 1:5000, including thematic overlay, such as soil values (LK 5 S).

There is a *low-cost version* made as *blue-print* that is available from local cadastral offices. In this case thematic overlays, such as the up-to-date cadastral layer, are mounted manually before reproduction; therefore there are two layers of film to be copied through. Thematic information – such as property boundaries – appears in black over the orthophoto background.
The more sophisticated *high-quality orthophotomap* is made at the BLVA being *reproduced on photographic paper*. In case thematic overlays are not yet available in digital form, the analog films are scanned. Afterwards the dataset for the orthophotomap and the overlay(s) is/are added to the DOP-Post-Script-file and printed together in one step on one single sheet of film. Thematic information can be shown on this output either in black or in white overlaid onto the orthophoto background (see Figure 2 and Figure 3).
In a similar way *orthophotomaps 1:10000 (LK 10)* are produced for map revision as 1/9-sheets of the *topographical map 1:25000* (TK 25). These are also available for the public on demand.
Large-format maps of appropriate output scales (for example showing a complete view of a town or the center of a larger city, neglecting mapsheet frames) can be derived through mosaicking from existing orthophoto data sets (see Figure 4).

6. CONCLUSIONS

During 2 1/2 years of operation digital orthophotography has proved to be very effective and successful. In 1996 more than 3600 orthophotomaps were produced from digital orthophotos (without counting different editions or duplicate prints of the same mapsheet), which means an increase of approx. 150% compared to the year before and this is not the end. In order to manage all information about aerial images, DOPs, maps etc. and to have immediate access to the orthophoto data files itself, a powerful database is absolutely necessary.

7. ACKNOWLEDGEMENTS

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Figure 1: Orthophoto map (reduced in scale).

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Figure 2: Orthophoto map (detail, reduced in scale)
with cadastral overlay in white (top) and black (bottom) resp.

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Figure 3: Orthophoto map (detail, reduced in scale)
with contour overlay in white (top) and black (bottom) resp.

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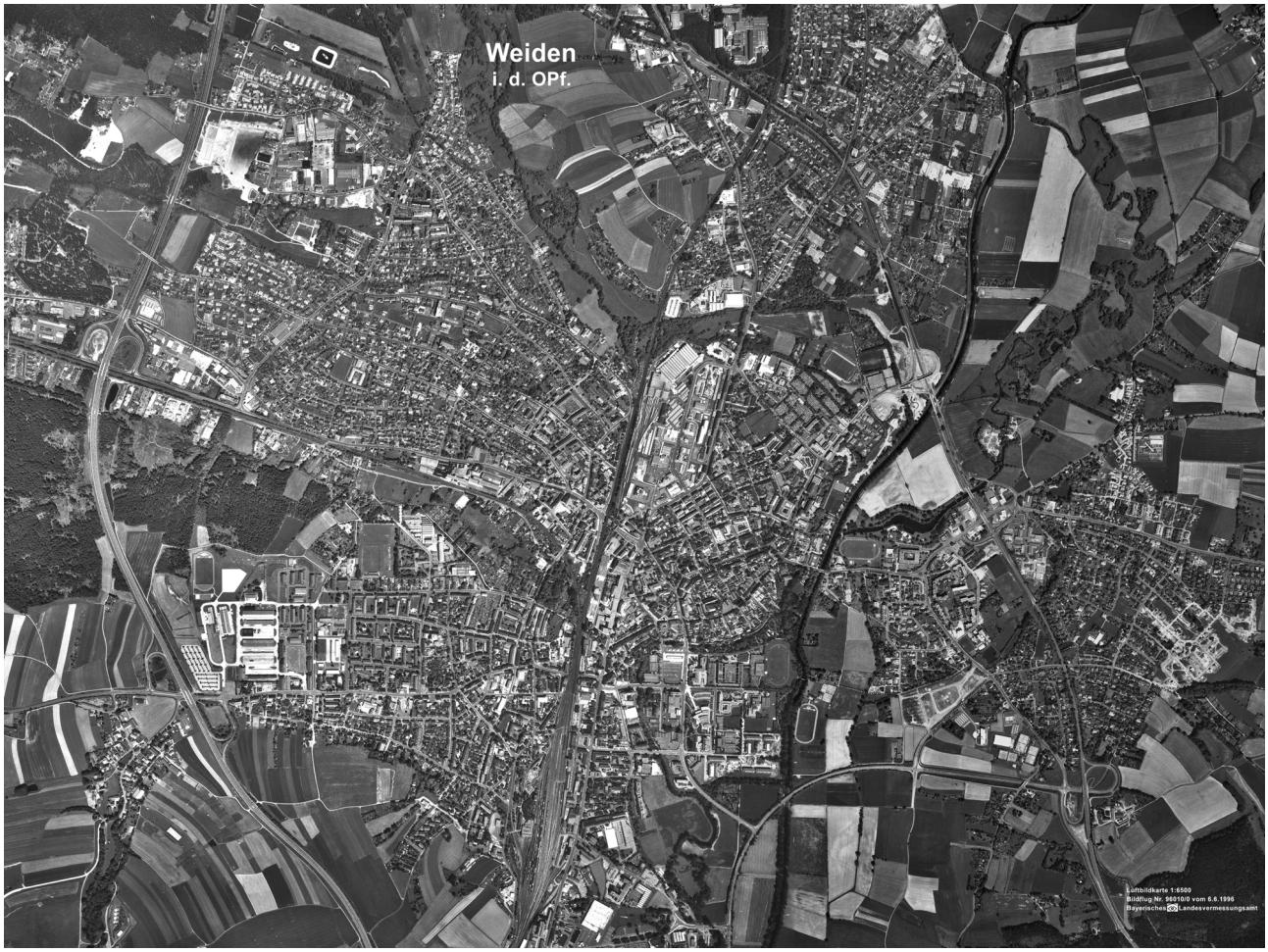

Figure 4: Orthophoto mosaic *Weiden i. D. Opf.* (from 2 images).