

A CONTRIBUTION TO DIGITAL ORTHOPHOTO GENERATION

Werner Mayr
Chair of Photogrammetry
Technical University of Munich
Arcisstr. 21, D 8000 Munich 2
Federal Republic of Germany

Christian Heipke
Industrieanlagen - Betriebsgesellschaft (IABG)
Einsteinstr. 20, D 8012 Ottobrunn
and
Chair of Photogrammetry
Technical University of Munich
Arcisstr. 21, D 8000 Munich 2
Federal Republic of Germany

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Abstract

This paper reflects an approach of generating orthophotos digitally. The main subjects are the quality of the orthophoto and the operational data flow. Thus, the pixel-by-pixel method and the incorporation of geomorphological information are components of a high-quality orthophoto. Algorithmic adaption to a super-computer and patching are used for performance optimization. First results are presented.

1. Introduction

The need for up-to-date maps in modern economy and infrastructural planning is growing constantly. One uses topographical (1:25,000) or cadastral (1:5,000; 1:1,000) or even orthophoto maps (1:10,000; 1:5,000). The basic resources in modern map revision are orthophotos. In Bavaria, FRG, orthophotos with a scale of 1:10,000 are used to revise the topographical map 1:25,000 (TK 25) [9]. In practice the generation of orthophotos is performed today by computerized orthoprojectors like the Wild OR1 or the Zeiss Z2. These machines are controlled by minicomputers and require as input besides the analogue image, elements of interior and exterior orientation, and a preprocessed digital terrain model (DTM) stored in profiles. Replacing the analogue image by its density value matrix (=> **digital image**) allows for a rectification without the requirement of any mechanical projection device. This idea was proposed in several articles [2,3,7,8,12]. Thus, the computerized generation of orthophotos is becoming part of digital photogrammetry.

2. Basic principles, theoretical aspects

To obtain an orthophoto digitally one has to perform a digital image transformation which means the digital image has to be transformed from a central perspective projection into an orthogonal projection. This task requires the following input data:

- a digital image
- interior and exterior orientation values and
- a digital terrain model.

A digital image can be generated by a scanning device which subdivides the image into a square grid storing the density value of each cell, called pixel, linewise or columnwise. The width of one pixel typically varies between $12.5[\mu\text{m}]$ and $100[\mu\text{m}]$ from image to image. In the case of a colour image three density values for the red, green, and blue channel respectively are obtained. An overview on pixel sizes and the amount of data for a black and white aerial image ($23 \times 23[\text{cm}^2]$) can be found in [12].

Orientation parameters may originate from an aerotriangulation (exterior orientation) and from a camera calibration report (interior orientation). The primary DTM may be measured in a photogrammetric stereo model and is then interpolated to a secondary DTM with a locally complex data structure to take into account precise geomorphological information (e.g. break-lines).

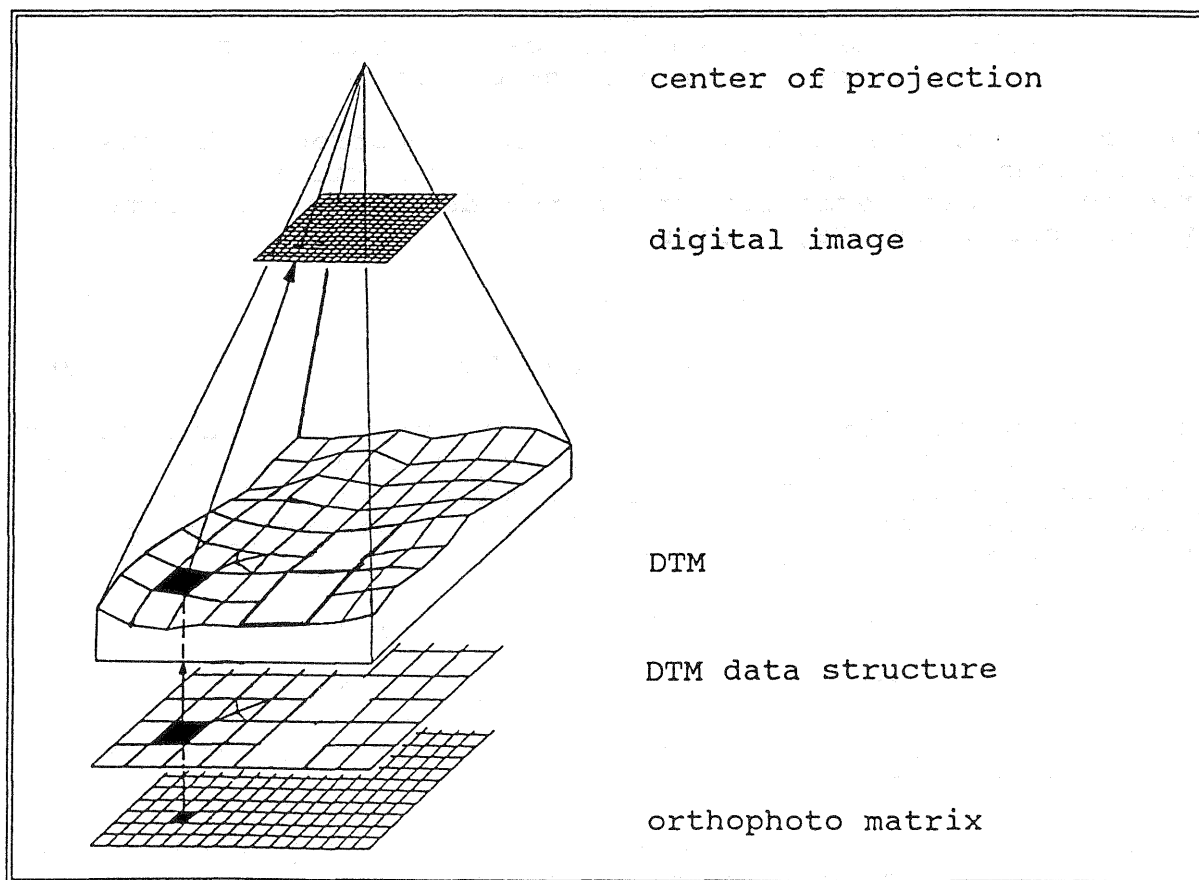


Figure 1

In principle there are two ways to perform the rectification. The first method starts from the image and projects each image pixel onto the object coordinate plane using the collinearity equations [12] and is called the **direct** method (or **top-down**). More advantages has the opposite way, called the **indirect** method [12] (or **bottom-up**) which will be explained in more detail below. Figure 1 shows this second method using the program package HIFI-88 [6] and its data structure for elevation derivation.

Starting in the orthophoto matrix each pixel (row_{OP}, col_{OP}) is scaled and possibly rotated to plane object coordinates XY (the system of the DTM). Then the elevation is interpolated using the algorithm of the DTM program available.

$$Z = f(X,Y); [m] \quad (1)$$

This object point P (XYZ) is projected into the image applying the collinearity equations (2a), (2b):

$$x = x_0 - c \frac{r_{11}(X-X_0) + r_{21}(Y-Y_0) + r_{31}(Z-Z_0)}{r_{13}(X-X_0) + r_{23}(Y-Y_0) + r_{33}(Z-Z_0)}; [mm] \quad (2a)$$

$$y = y_0 - c \frac{r_{12}(X-X_0) + r_{22}(Y-Y_0) + r_{32}(Z-Z_0)}{r_{13}(X-X_0) + r_{23}(Y-Y_0) + r_{33}(Z-Z_0)}; [mm] \quad (2b)$$

with: x_0, y_0 : image coordinates of principal point [mm]
 c : focal length [mm]
 X_0, Y_0, Z_0 : coordinates of the camera station [m]
 $r_{ij}, i,j=1,3$: functions of phi, omega, kappa

The image coordinates (x,y) have to be **de-corrected** because of the influence of radial distortion, earth curvature and refraction. These terms sum up to the de-correction terms dx, dy; see equations (3a), (3b):

$$x' = x - dx; [mm] \quad (3a)$$

$$y' = y - dy; [mm] \quad (3b)$$

The decorrected image coordinates (x',y') then have to be transformed into the pixel coordinate system of the digital image using e.g. an affine transformation (4a), (4b) with the fiducials as identical points. The location (row_{DI}, col_{DI}) of each image pixel is obtained by:

$$col_{DI} = a_0 + a_1x' + a_2y'; [pixel] \quad (4a)$$

$$row_{DI} = b_0 + b_1x' + b_2y'; [pixel] \quad (4a)$$

with: $a_0, a_1, a_2, b_0, b_1, b_2$ parameters of an affine or Helmert transformation.

Herein the center of the orthophoto pixel is projected. The affine transformation can be interpreted as an attempt for correcting for film shrinkage as well as nonorthogonality and

different scale factors of the scanning device. This model may have to be refined. Investigations are currently under way. As the location row_{DI}, col_{DI} of the projected orthophoto pixel center is usually not the center of an image pixel, the density value at that location has to be resampled. Different methods of interpolation such as bilinear, bicubic or Lagrange are in common use in image processing [11]. An overview on these interpolations, the number of math-operations, and an estimation on the error properties can be found in [12]. The density value obtained represents the result of the rectification process at each pixel. It is stored in the orthophoto at row_{Op}, col_{Op} . The described process has to be performed for each orthophoto pixel, thus generating one orthophoto.

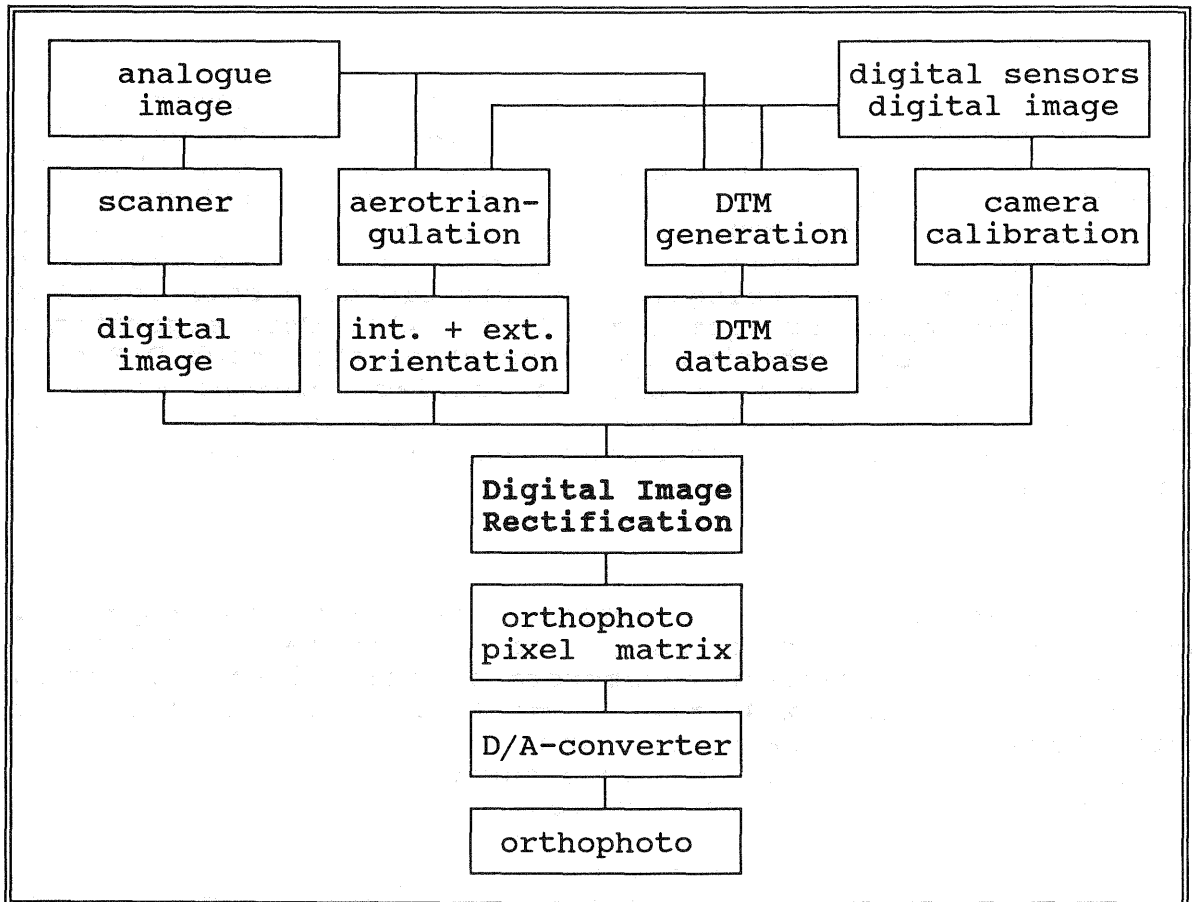


Figure 2

All this can be executed on every computer provided there is enough disc space, and the machine is reasonably fast. To get a hardcopy of the computed orthophoto one needs a D/A-converter. Figure 2 summarizes this process in general.

3. Computational aspects

3.1 Necessary software and hardware configuration

The quality of the orthophoto strongly depends on the input data. Good orientation parameters are generated by an aerotriangulation. For the derivation of the elevation of an ortho-

photo pixel, DTM software is needed. The softcopy of the image is generated by a scanner (A/D converter), and the hardcopy is produced by a D/A converter.

Because digital orthophoto generation is a very CPU-time intensive process, it is recommended to use a powerful computer with a large amount of disc and memory space. A super-computer or a parallel computer would even be better suited to accomplish this task. For the necessary quality control a display station is required. Before computing the orthophoto the quality of the image should be inspected (e.g. for dust particles). Last not least the software for digital image rectification (**DIR**) is needed.

3.2 Algorithmic adaption

3.2.1 Anchorpoints

To reduce the amount of computation the method of **anchorpoints** was introduced [12]. Equations (1) to (4b) are applied to the DTM grid points only. This grid is much coarser than the orthophoto grid. Then, an affine transformation between this trapezoid (projected DTM mesh) and its ground projection in object space is established. Thus, one is able to transform each orthophoto pixel being inside this DTM grid cell into the image without applying equations (1) to (4b). This algorithmic speed-up, however, inherits the assumption that each DTM cell consists of at the most a bilinear surface element which is not always true. Geomorphological information can only be included, when complex data structures are used. Resampling is done for each orthophoto pixel.

3.2.2 Pixel-by-pixel

Another possibility is to rectify the image **pixel-by-pixel** and to reconfigure equations (1) to (4b) by taking advantage of some of the invariant parameters in this algorithm namely of the rotation matrix R (r_{ij} , $i, j=1, 3$) and the transformation parameters $a_0, a_1, a_2, b_0, b_1, b_2$. Writing (2a) and (2b) in a slightly different form by incorporating (3a), (3b), (4a), (4b) into the collinearity equations yields (5a), (5b):

$$\text{col}_{DI} = \tilde{x}_0 - c \frac{\tilde{r}_{11}(X-X_0) + \tilde{r}_{21}(Y-Y_0) + \tilde{r}_{31}(Z-Z_0)}{\tilde{r}_{13}(X-X_0) + \tilde{r}_{23}(Y-Y_0) + \tilde{r}_{33}(Z-Z_0)} + \text{dcol}; \quad (5a)$$

$$\text{row}_{DI} = \tilde{y}_0 - c \frac{\tilde{r}_{12}(X-X_0) + \tilde{r}_{22}(Y-Y_0) + \tilde{r}_{32}(Z-Z_0)}{\tilde{r}_{13}(X-X_0) + \tilde{r}_{23}(Y-Y_0) + \tilde{r}_{33}(Z-Z_0)} + \text{drow}; \quad (5b)$$

with: $\tilde{x}_0 = a_0 + a_1x_0 + a_2y_0$; [pixel]
 $\tilde{y}_0 = b_0 + b_1x_0 + b_2y_0$; [pixel]

$$\begin{aligned} \tilde{r}_{11} &= r_{11}a_1 + r_{12}a_2; & \tilde{r}_{12} &= r_{11}b_1 + r_{12}b_2; & \tilde{r}_{13} &= r_{13}; \\ \tilde{r}_{21} &= r_{21}a_1 + r_{22}a_2; & \tilde{r}_{22} &= r_{21}b_1 + r_{22}b_2; & \tilde{r}_{23} &= r_{23}; \\ \tilde{r}_{31} &= r_{31}a_1 + r_{32}a_2; & \tilde{r}_{32} &= r_{31}b_1 + r_{32}b_2; & \tilde{r}_{33} &= r_{33}; \end{aligned}$$

$$\text{dcol} = -(a_1dx + a_2dy); \quad \text{drow} = -(b_1dx + b_2dy); \quad [\text{pixel}]$$

This rearrangement eliminates (4a) and (4b) completely. The corrections draw, dcol can be precomputed and stored in form of correction look-up-tables covering the whole image.

3.3 Super-computer

With the friendly support of IABG Corp., Ottobrunn, FRG, DIR is about to be installed on a SIEMENS VP-200 super-computer. This is a vector computer with a theoretical peak performance of 570 MFLOPS and 58 MB memory. The computer works in background only and is served by a SIEMENS 7.890F computer which is accessible interactively. Figure 3 shows the scheme of this computer configuration.

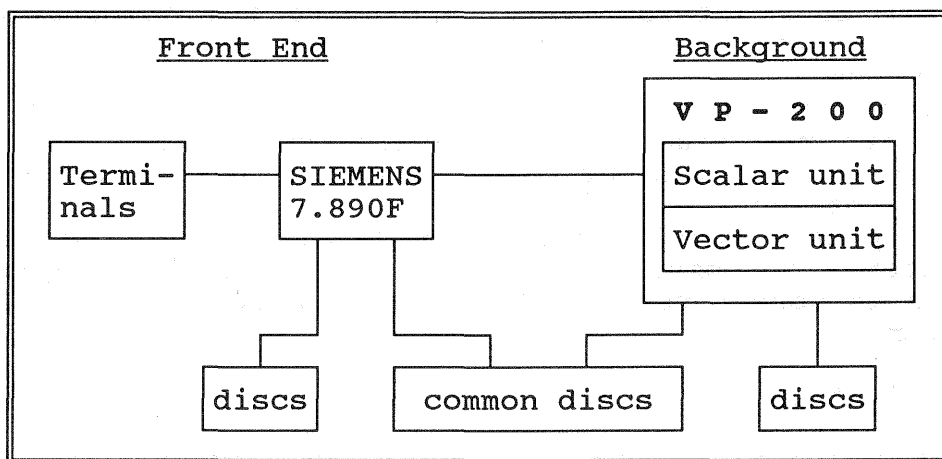


Figure 3

3.4 Vectorization

To take full advantage of the vector computer one has to adapt the program code to the hardware configuration of this machine. This is called **vectorization** [4]. The compiler (FORTRAN77) supports this process by indicating where vectorization is possible, where not, and where there are mixed data structures. Not vectorized code is processed on the **scalar** unit of the vector computer which is another SIEMENS 7.890F computer. Vectorization performed by the compiler is called **autovectorization**. The so called **handvectorization** still has to be done interactively. This involves mainly a rearrangement of the algorithm and an introduction of dummy-vectors. The length of DO-LOOPS (vector length) has to be adjusted to the hardware peculiarities. Special care has to be taken when IF-statements, subroutine calls or intrinsic functions (e.g. sin, cos) are vectorized [5]. Sometimes a completely different (vector-) formulation of the problem with regard to the vectorization techniques explained above is required.

3.5 Parallelization

Parallelization should be done after vectorization, because the ideal parallel machine consists of several vector processors working in parallel. In the specific case of DIR this can be achieved by subdividing the orthophoto area in equally sized patches each fitting into the memory of one processor of

the parallel machine. Each processor then works on the set of equations discussed in 2.

4. Realization

DIR was developed on a DEC VAX 11/750 computer in FORTRAN77 and is currently being installed on the super-computer. It is organized into three parts.

4.1 Preprocessing

Here, all input data can be entered, edited, listed, deleted, and copied. Also all computations possible to be performed in advance are done interactively, including the computation of the rotation matrix elements, transformation parameters and DTM statistics.

The interior orientation is determined by matching an ideal fiducial with the true fiducial analogous to [1]. As result one obtains the non-integer pixel values of that fiducial with an accuracy of about 0.3 pixels.

Additionally this module performs several checks. The preprocessing step also comprises a visual check of the image. However, this is done outside DIR using an existing image processing system.

4.2 Rectification

This is the actual workhorse of DIR. It performs the rectification pixel-by-pixel. The orthophoto is processed patchwise. For each patch the corresponding image patch is loaded into memory and then processed. The DTM is loaded usually into memory and remains there.

4.3 Postprocessing

This part is designed, but not completely realized yet. Analysis, quality control, mosaiking and radiometric transformations will be part of postprocessing.

5. First results

For the first test a set of four aerial images originating from two crossing flight paths (intersection angle 40[degrees]) was used. From each path two adjacent images forming two stereo models were taken. The approximate image scale was 1:30,000, the flying height 4,500[m], and the focal length 152.72[mm]. Each image was scanned completely (pixel size 25x25[μm^2]) by a HELL CTX 330 scanner. To reduce the amount of data for test purposes an area of 2048x2048 pixels was cut out of each image. The orthophoto scale was 1:10,000. The pixel size was 62.5x62.5[μm^2]. Due to the intersection angle one could not use the whole area of the sub-images as orthophoto area. One area which was contained in all four sub-images was chosen to be rectified.

The DTM used was derived by HIFI-88 from a primary DTM of 20[m] grid spacing and geomorphological information measured

in a stereo model. The orientation parameters were obtained from photogrammetric measurement and an aerotriangulation. The computation time for one orthophoto was 25[minutes]. A first visual control consisted of loading one orthophoto into the red channel and another one of the other flight path into the green channel of the screen of the image processing system. No errors were detected, since no red or green areas could be found.

Another control was done by measuring identical points in the orthophoto (Easting, Northing) and in the stereo model (Easting, Northing, Elevation). The comparison of orthophoto coordinates and stereo model coordinates resulted into an accuracy of $\sigma_E=91[\mu\text{m}]$ and $\sigma_N=40[\mu\text{m}]$ in the orthophoto.

In a second step a complete orthophoto (8000x8000[pixel²] or 50x50[cm²]) was generated.

Table 1 gives an overview on computing times comparing the anchorpoint method [2,12] and the pixel-by-pixel method.

Arbiol [2] anchorpoint method			
Computer	CPU-perform.	# pixels	time/(1000pix.)
VAX 11/750	1.0 MIPS	2400x2400	0.081 [sec]
VAX 11/780 equi. with array chip	5.0 MFLOPS	2400x2400	0.030 [sec]
Wiesel [12] anchorpoint method			
Computer	CPU-perform.	# pixels	time/(1000pix.)
PRIME 650	0.5 MIPS	2000x2000	0.282 [sec]
SIEM. 7880	6.6 MIPS	2000x2000	0.015 [sec]
CYBER 205	80 MFLOPS	2000x2000	0.014 [sec]
Mayr pixel-by-pixel method; development vers.			
Computer	CPU-perform.	# pixels	time/(1000pix.)
VAX 11/750	0.6 MIPS	1440x1280	0.817 [sec]
μ VAX II	1.0 MIPS	8000x8000	0.906 [sec]

Table 1

6. Outlook and conclusions

The geometric accuracy is not any longer influenced by an orthoprojector but only by the quality of the input data and the mathematical model. First results show that the visual quality of the orthophotos is the same as the one of the aerial images without any additional enhancements. It can be directly input into an image processing system and processed easily to an orthophoto map [10]. Thus, the digital generation of orthophotos can be automated almost completely.

DTM data bases are being expanded systematically, and aerotriangulations are being available as well. Besides this, high precision scanners and powerful minicomputers are accessible.

A disadvantage is the long computation time for the pixel-by-pixel method on minicomputers. However, this fact will be overcome by applying super-computers or parallel computers. Orthophotos may be generated in any size independently of map formats, input images, and flight paths. Moreover, digitally generated orthophotos can easily be linked into geo information systems (GIS) and therefore gain even more versatility.

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