Automatic Orientation of Aerial Images by Means of Existing Orthoimages and Height Data

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ABSTRACT
The theoretical background to a new approach for the automatic orientation of single images is given. The test data, a colour ortho image and a height model, are analyzed and improvements for the production of a new ortho image and for the storage of other data are made. Such data and the proposed procedures could facilitate the automatic production of new orthoimages.

KURZFASSUNG
Automatische Orientierung von digitalen Luftbildern mittels existierender Orthobilder und Höhendaten. Der theoretische Hintergrund für eine neue Lösung zur automatischen Orientierung von Einzelbildern wird gegeben. Die Ausgangsdaten für einen Test, ein farbiges Orthobild und ein Höhenmodell, werden analysiert und daraufhin Vorschläge sowohl zur verbesserten Orthobildherstellung als auch für die Speicherung von zusätzlichen Daten gemacht. Derartige Daten sowie die vorgeschlagenen Prozeduren können die automatische Herstellung von neuen Orthobildern erleichtern.

1. INTRODUCTION

The orientation of the images is the first step in the production of orthoimages. If orthoimages have to be renewed every 2-5 years, the existing orthoimages can be used for a fully automatic orientation process. It is the goal of this paper to outline a strategy for a solution of this task. This paper is based on a current test of the European Organization for Photogrammetric Research (OEEPE), where for a given test material

a) the best methods with regard to feasibility, speed and accuracy should be found by the participants

b) demands for new orthoimages and other data are to be defined in order to enable the automatic orientation of new images.

Automated methods will help mapping organizations as well as users of geodata to update orthoimages or derive thematic information from orthoimages. OEEPE has recognized the need for an automated solution to such practical tasks and put the working group 1.3 in action. The members of the working group and possibly other people interested in the tasks will try to come up with solutions and suggestions in the next 6-8 months. This paper will therefore try to propose a solution and thereby stimulate research for new methods in automatic orientation.

2. DESCRIPTION OF THE TASK

The orientation of single images is part of the production of new orthoimages. Fig. 1 shows a schematic diagram of the steps and data involved in the production of orthoimages. More detailed information on the production of orthoimages can be found in (Höhle, 1996).

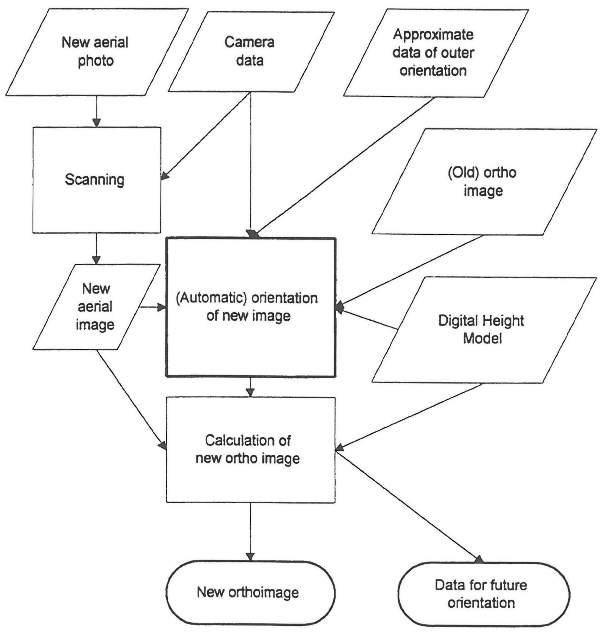

Fig. 1 General process in the production of orthoimages

The determination of the outer orientation of an aerial image requires camera data, approximate data for the outer orientation, and control points with known ground coordinates and observed image coordinates. For an automatic determination the control points are replaced by control structures and a correspondence between (old) orthoimage structures and (new) aerial image structures has to be found at various positions. The (old) orthoimage is geo-referenced which means that each pixel has XY- coordinates in a reference system. From an (existing) digital height model (DHM) Z-values can be interpolated so that each pixel of the orthoimage is known by XYZ coordinates.
The matching between parts of the orthoimage and of the aerial image can be based on the values of the pixels (for examples colours) and on two dimensions. A template has to be generated from one of the images and moved within a search area of the other image in order to find the best correspondence or fit. The template serves as the measuring "mark", and the best fit is found by a criterion, for example when the correlation coefficient has its maximum. More details on correlation can be found in (Höhle, 1997). The influence of the terrain has to be taken into account when a template is generated. Because the outer orientation of the new image is known approximately only, the search area has to be rather large. An image pyramid as well as robust adjustment have to be used in order to find a safe and fast solution. It is obvious, that the whole production of a new orthoimage can be carried out automatically if the orientation of the image can be solved automatically. The production of new orthoimages has to go along with the generation of other data which can ease the orientation of the next generations of orthoimages.

3. THE OEEPE TEST MATERIAL

The test material of the OEEPE uses colour images of open country sites. The area has several forests, many fields and a few farm houses. In such areas coloured orthoimages offer many advantages and applications in comparison with vector maps. Such orthoimages are produced for large areas. Renewal or updating has to be carried out locally at intervals of 2 -3 years or country wide at 5 -7 years. The photography of the test was taken in June 1995 and 1997 respectively. The following details of the test material are important to the methods for automatic orientation.

Orthoimage:
Pixel size on the ground: 0.8 m
Image size: 5000 pixel x 7500 pixel
Radiometric resolution/band: 256
Amount of data: 110 Megabyte
Format: TIFF

New aerial image:
(Average) photo scale: 1:27 000
Camera constant: 152 mm
Pixel size in the image: 30 my
Radiometric resolution / band: 256
Image size: 7729 pixel x 7804 pixel
Amount of data: 177 Megabyte
Format: TIFF

Height model:
Grid interval: 20 m x 20 m
Area: 6 km x 4 km
Accuracy: 0.5 m
Format: ASCII

The heigths were measured by an experienced operator in an Analytical Plotter on top of all the objects. The fig. 2 shows the coverage of the different images and of the height model.

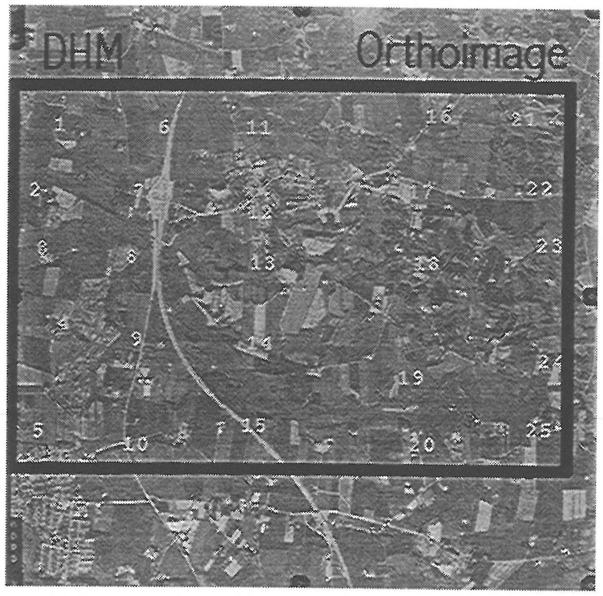

Fig.2 Coverage of orthoimage,height model and new aerial image. The bright numbers indicate positions of the check pixels.

In order to check the results of the orientation, 25 pixels of the new image have to be coordinated in the ground coordinate system. These check pixels are central pixels of an 31 pixel x 31 pixel large image section. Further data of the test are the calibration report of the camera, detailed descriptions of the various data as well as an overview image for the positions of the check pixels. All the data are delivered on a CD ROM which contains 300 Megabytes.

4. SYSTEM REQUIREMENTS

As it can be seen from the data material the amount of data is relatively large. Professional systems for the production of orthoimages or stereo digitizing do use UNIX or PC based systems. Also the World Wide Web and a browser can possibly be used as a computing and storage platform.

There are various professional programs which can partly be used to solve the given task. For example, the orientation of digital images can be carried out manually or semi-automatically, by the following programs: Match-T (Inpho), RECTIFY (Intergraph), Phodis-O (LZW). However, the full-automatic orientation by means of existing ortho- image and height model data is new and, therefore, new programs have to be written or a combination of existing and new programs has to be applied.

5. SOMETHEORETICAL BACKGROUND TO AUTOMATIC OUTER ORIENTATION

5.1 Colour images

Colour images consist of three matrices: one for red, one for green and one for blue colour. These so-called RGB images can be transformed into IHS images, and the intensity component can be used for the calculation of the orientation parameters. The amount of data to be handeld is then a third only. The transformation formulae are the following:

$$I = (M + m) \cdot 0.5$$

where:

I ... Intensity component,
M ... maximum (R,G,B),
m ... minimum (R,G,B).

More details on colour transformations can be found in (Kraus, 1990). Some of the professional systems can carry out such a transformation.

5.2 Relation between image and orthoimage

The relation between the image and the orthoimage is expressed by the collinearity equation:

$$\begin{bmatrix} X \\ Y \\ z \end{bmatrix} = m \cdot D \cdot \begin{bmatrix} x \\ y' \\ -c \end{bmatrix} + \begin{bmatrix} X_o \\ Y_o \\ Z_o \end{bmatrix} \qquad (1)$$

where:

c ... camera constant
x', y' ... image coordinates
X_o, Y_o, Z_o... coordinates of the perspective center
m ... scale factor
D ... matrix of rotation
X,Y, Z ... ground coordinates

The scale factor can be eliminated if the Z-(height-) value is known from a height model:

$$m = (Z-Z_o)^{-1} \cdot (a_{31} \cdot x' + a_{32} \cdot y' - a_{33} \cdot c) \qquad (1a)$$

where:
a_{ij} ... coefficients which contain sinus and cosinus of the rotation angles

The ground coordinate can be calculated then by:

$$X = m \cdot (a_{11} \cdot x' + a_{12} \cdot y' - a_{13} \cdot c) + X_o \qquad (1b)$$
$$Y = m \cdot (a_{21} \cdot x' + a_{22} \cdot y' - a_{23} \cdot c) + Y_o$$

These formulae are used for the so-called monoplotting. They can be used as fundamental equations for the adjustment procedures in order to determine the most probable values for the parameters of the orientation : X_o, Y_o, Z_o, w, j, k. Observations are in this case X and Y, its residuals are to be minimized. If no angles are available at the beginning of the calculations, simplified formulae can be used in order to compute approximate positions:

$$X = m_b \cdot x' + Xo$$
$$Y = m_b \cdot y' + Y_o \qquad (1c)$$

where: m_b ... average photo scale.

5.3 Photo coordinates

The aerial image is given in the coordinate system of the scanner, the units are pixels. It consists of 7729 rows and 7804 columns. In addition, the size of the pixel and the parameters of the transformation are known from the scanning process. Image coordinates are obtained by:

$$\begin{bmatrix} row \\ col \end{bmatrix} = \begin{bmatrix} a & b \\ c & d \end{bmatrix} \cdot \begin{bmatrix} x' \\ y' \end{bmatrix} + \begin{bmatrix} row_o \\ col_o \end{bmatrix} \qquad (2)$$

where:

row, col	...	scanner-coordinates
x',y'	...	photo-coordinates
a,b,c,d	...	transformation parameters

The photo coordinates may be found by inverting the formulae (2). Fig. 3 shows the coordinate system of the image and the scanner.

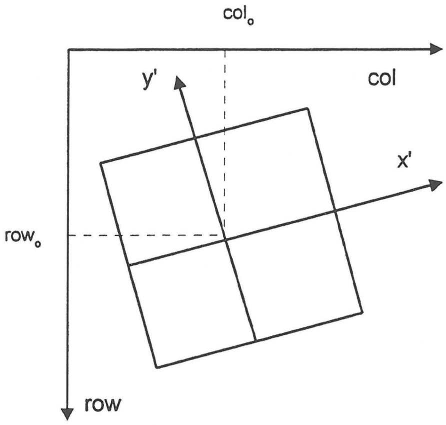

Fig. 3 Coordinate system of the scanner and the image

5.4 Orthoimage

The orthoimage of the test material consists of 4 orthoimages. Each one has coordinates in the Danish map projection (system 34J) for the 4 corners which are labelled (NW,NE,SE,SW). The first coordinate (Y) is Northing, the second (X) has its positive axis to the west. The units are meter. The corner coordinates correspond to the corners of the pixels (compare fig. 4). Furthermore the corners of the orthoimages are given in pixel coordinates as well. Its origo is in the left upper corner of the orthoimage and at the upper left corner of the pixel.
The transformation equation is therefore:

$$\begin{bmatrix} Y \\ X \end{bmatrix} = \begin{bmatrix} Y_o \\ X_o \end{bmatrix} - gsd \cdot \begin{bmatrix} row \\ col \end{bmatrix} \qquad (3)$$

where:
gsd .ground sampling distance (pixel size on ground)

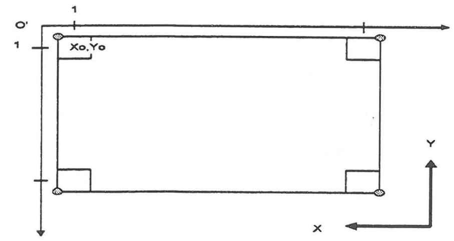

Fig.4 Coordinate systems of the ortho-images

In this way the precise corner coordinates are obtained in meter. However this leads to a change of the origo with regard to the pixel. For the sake of a constant origo we will position a new origo (O') half pixel outside of the orthoimage matrix. Then the ground coordinates always refer to the center of the pixel when multiplying matrix coordinates with the pixel size (gsd):

$$\begin{bmatrix} Y \\ X \end{bmatrix} = \begin{bmatrix} Y_o + 0.5 \cdot gsd \\ X_o + 0.5 \cdot gsd \end{bmatrix} - gsd \cdot \begin{bmatrix} row \\ col \end{bmatrix} \qquad (4)$$

5.5 Interpolation in the heigth model and the images

The given height model is structured as a grid of height values. In oder to interpolate a height for a XY-position a bilinear interpolation is usually applied:

$$Z = A \cdot X + B \cdot Y + C \cdot X \cdot Y + D \qquad (5)$$

The constants A, B, C and D are determined from 4 equations using the heights of the directly adjacent four grid points. In a similar way we could interpolate the intensity values within an orthoimage or an aerial image. In image processing one often uses the weighted mean. The weights are the distance from the corners of the adjacent pixels (compare fig. 5):

$$\begin{aligned} I = \; & (1-c)(1-d) \cdot I(row,col) \\ & + c \cdot (1-d) \cdot I(row,col+1) \\ & + (1-c) \cdot d \cdot I(row+1,col) \\ & + c \cdot d \cdot I(row+1,col+1) \end{aligned} \qquad (6)$$

where:
I ... intensity value,
c, d ... distances from upper left pixel

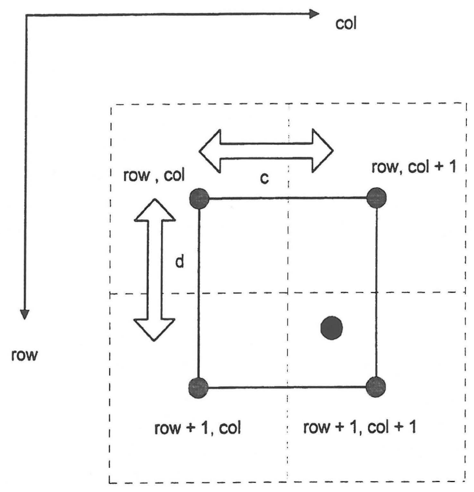

Fig. 5 Bilinear Interpolation of an intensity value

5.6 Matching of the orthoimage and the aerial image

Observation data can be established if parts of the orthoimage are matched with the aerial image. The image parts have to be sufficiently large, well distributed over the image area and with a good structure in order to find a good correlation. It should be tested by means of an interest operator whether there exists a good structure. Details can be found in (Kraus, 1993, p.368). The correlation procedure is then the following: A small image part called template is moved pixel by pixel over a somewhat larger image part (search area) and at each location a correlation coefficient is calculated after:

$$r = \frac{(I_1 - I'_1)\cdot(I_2 - I'_2)}{\sqrt{(I_1 - I'_1)^{2}\cdot(I_2 - I'_2)^{2}}} \qquad (7)$$

where:
r... correlation coefficient
I_1... intensity value of a pixel in the template area
I_2... intensity value of a pixel in the search area
I'_1, I'_2... average value of the template or search area respectively

The position where the correlation coefficient has its maximum value is the position of best fit. Subpixel values can also be found by more sophisticated formulae (compare Höhle, 1997). The template is formed in the orthoimage. Its generation is influenced by the height model and by the collinearity equation. The **suggested procedure** is then the following:

a. The central pixel coordinates of the selected aerial image part are transformed into photo coordinates by the inversed equation (2). A height value is interpolated from the height model using an approximate XY-position which is derived by the simple relation (1c). The calculations are repeated until no change in position occurs.

b. The obtained position is transformed into pixel coordinates by the inverse of (4). It serves as the central pixel of the template consisting of , for example, 21 x 21 pixels. The size of the pixel should correspond to the one of the orthoimage in the selected level of the image pyramid.

c. The intensity value of this central pixel (and of all the other pixels) has to be found in the aerial image using the reverse calculations and the bilinear interpolation after (6) using the four direct adjacent pixels .

d. In the orthophoto a search area is established. It should be somewhat larger than the template, for example 31 x 31 pixel. Its center is the same as the one of the template (compare step b). The correlation computations after (7) lead to the pixel coordinates of the best fit. A transformation after formulae (4) has to be carried out in order to obtain ground coordinates.

5.7 Calculation of orientation data

The result of the matching are ground coordinates for a pixel of each search area. With 10 to 25 of these observables the outer orientation can now be calculated using robust adjustment procedures. This leads to corrections of the outer orientation. The whole process is repeated leading to new corrections and further improved orientation data.The resolution of the search and template area is changed in any new orientation step. A detailed description of an algorithm for the solution of outer orientation can be found in (Slama, 1980).

6. TESTING OF THE RESULTS

In order to test the quality of the automatically derived outer orientation there are different possibilities. The residuals in the ground coordinate system should be small and without blunders. The calculated orientation data should have standard deviations which are equal or better than those obtained from a manual process. Furthermore, the OEEPE test requires ground coordinates for 25 pixel. These are the central pixel of 31 pixel x 31 pixel wide patches which are regularly distributed over the (new) aerial image.

7. DEMANDS TO NEW ORTHOIMAGES AND OTHER DATA

Successful automated orientation of aerial images by means of existing orthoimages, DHMs, and other stored information will require special measures. When new orthoimages are created special features can be incorporated in such data so that the next generation of orthoimages will fulfill the demands of an automated production. Such preparations will start the planning of the photomission. The season and the point of time (height of the sun) should be equal. The position of the camera (and possibly the tilts of the camera axis) should be recorded by GPS- (and INS-) equipment thus making sure that good approximations for the outer orientation are available. The scanning of the photos should include the (automatic) measurement of the fiducials, so that the transformation parameters between image and photo are known. With this information the data processing is eased and can occur faster or in smaller (less expensive) computers. Ortho image and new image should be available as image pyramids with 4-6 levels of resolution. This increases the amount of data by a third only. The stored height model should include information on the land use. By this measure terrain types such as built-up or wooden areas could be avoided in the matching process. Special control information from house roofs and the derived wire frame models could be stored as well. This approach is chosen by the Landesvermessungsamt Nordrhein-Westfalen, Germany (Läbe et al. , 1996).

8. OUTLOOK

The forthcoming OEEPE test will show which are the best approaches in the automatic orientation of single images. It will also require the implementing of the formulae into efficient programs with a good user interface. It is the hope of the author that the OEEPE test will give new answers to this important task of the photogrammetric praxis.

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