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Towards the Full Automatic Production of Orthoimages

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Summary: Spatial coordinates of road crosses are derived from a topographic database and small image patches are then extracted from an existing (old) orthoimage at these positions. These patches are used as templates and matched with parts of a new aerial image. From several corresponding pixels the exterior orientation of an (new) aerial image is derived. This first step in the production of an orthoimage is carried out automatically and results with practical data are presented. This automated process requires some special measures to detect and eliminate blunders in the measurements. The methodology is described and the effect of selectable thresholds is investigated. The obtained results demonstrate that the automation of the exterior orientation is possible.

Zusammenfassung: *Auf dem Wege zur vollautomatischen Herstellung von Orthobildern.* Die räumlichen Koordinaten von Straßenkreuzungen werden aus einer topographischen Datenbank abgeleitet und kleine Bildausschnitte werden an diesen Positionen aus einem (bestehenden) Orthobild entnommen. Diese Bildausschnitte werden als Mustermatrizen benutzt und Teilen eines neuen Luftbildes zugeordnet. Aus mehreren sich entsprechenden Bildelementen wird die äussere Orientierung eines neuen Luftbildes abgeleitet. Der erste Schritt in der Herstellung eines Orthobildes erfolgt automatisch und Ergebnisse mit praktischen Daten werden präsentiert. Dieser automatisierte Prozess erfordert einige spezielle Maßnahmen, um grobe Fehler in den automatischen Messungen zu erkennen und zu eliminieren. Die Vorgehensweise wird beschrieben und die Wirkung von Schwellwerten untersucht. Die erhaltenen Ergebnisse zeigen, dass die Automatisierung der äusseren Orientierung eines Luftbildes möglich ist.

1 Introduction

The demand for actual geodata requires a quick production and a regular updating of such information. The orthoimages are a source for new map data and map data can be digitized from the screen with a sufficient accuracy. Orthoimages are also used as a layer in a Geographic Information System (GIS) and vector map data and height information can be superimposed. Deficiencies in the maps are easily visible. The orthoimage serves as a „window to the real world“ and it can be used by ordinary citizens as well as by experts of different fields.

The quick and easy production of orthoimages is one of the current topics in the mapping sciences. Existing topographic databases including orthoimages, height models and vector map data are used to derive the orientation data of new aerial images automatically. In the current production of orthoimages an aerotriangulation has to be carried out which requires special programs, know-how and many resources. All this will be avoided by the automated procedures. Several authors have proposed methods and in a recent OEEPE project results obtained with the same test material were published in HÖHLE 1999a. This investigation uses the method proposed in HÖHLE 1999b, however now with a higher degree of automation, and applies the method to the same test data.

2 Use of existing orthoimages and topographic map data

A topographic database includes several objects, which have enough structure and texture in their corresponding pictorial data

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(orthoimages and aerial images). Road crosses and their neighbourhood, for example, have such differences in tone or colour. Matching between patches of the new aerial image and of the orthoimage will then be possible. The extraction of the coordinates of road-crossings from a topographic vector database is a first step in finding appropriate areas for this matching process. The extraction of suitable objects has to be carried out automatically as well. Beside road crossings other objects may be selected, for example highways, paths, rivers, etc. All these objects are on the ground. Objects with height differences to the surroundings (houses, trees) will very likely cause problems in the correlation due to different perspectives and shadows. The objects have also to be time-invariant which means the time difference between the photography taking can be several years and the objects may change in that period of time. In this contribution the emphasis is on the intersection of objects in the theme "Traffic", that means crossings of roads. The tonal differences of roads and their surroundings are high and the changes over several years are small. Road crosses are therefore good candidates for a matching of images taken at different years.

3 Automatic extraction of road-crossings from a topographic database

Topographic map data store the centreline of roads. Road segments start or end at an intersection with another road. The road crosses are stored with the same coordinates at each road segment. If the database is searched after coordinates with the same values, road crosses can be found and extracted. The topographic database usually contains different types of roads, and all these road types intersect each other. In some areas too many road crossings may exist and in some other areas there will be no road crosses at all. This means, that a check for the proper distributions of road crosses as well as a thinning out or the use of additional objects could be included in the automatic extraction process. Modern topographic databases will also contain height information for the recorded objects, which avoids the use of a height model (DEM). If the roads have different heights at their crossings, the higher height value has to be used.

4 A strategy for an automated process

When the spatial coordinates of a road crossing are known, an image patch containing the road crossing and its surroundings are extracted from the orthoimage. Such an image patch will serve as a template in a searching process for a corresponding pixel in the new aerial image. The template is moved over a section of the aerial image in steps of one pixel and correlation coefficients are derived for each position. At the position where the correlation coefficient has its maximum value correspondence with the aerial image is found and the centre pixel of the patch is transformed into image coordinates. From several conjugate pixels the exterior orientation of the new aerial image can be derived by resection using the well-known collinearity equations.

Tab. 1 shows the various steps in automatic derivation of the exterior orientation of aerial images. Especially two problems in the process have to be solved. Firstly, the position of the search area depends on the quality of the approximations for the exterior orientation. If these approximations are very inaccurate a large search area has to be used which will result in higher computation times. Good positions for the coordinates of the perspective centre and the flying direction can be derived from the GPS-data, which are acquired by means of the navigation system. Secondly, blunders will occur in the automatic measuring of the corresponding image coordinates. A good strategy for detecting and eliminating blunders is necessary. Prerequisite is a large redundancy. Several measures can be applied such as thresholds for the maximum correlation coefficients, checks for sufficient distribution of road crosses over the image area and robust adjustment. Efficient methods

Tab. 1: Steps in the automatic derivation of exterior orientation parameters including the input and output.

input	steps	output
topographic map data base	searching for road crossings	spatial coordinates of road crossings
(old) orthoimage	extraction of orthoimage patches	templates
(new) aerial image approx. exterior orientation	extraction of image patches	search areas
measures for blunder detection	matching of patches	image coordinates
measures for blunder detection	resection	final exterior orientation

for eliminating the blunders are crucial for an automated process and the effect of these methods will be discussed in the following chapters.

5 Tests with practical data

In order to test the described procedures practical data were used. The data set includes one aerial image, four orthoimages and a topographic vector database. The aerial photograph was taken 25 month later than the one used for the (old) orthoimage. Several changes had occurred in the landscape due to construction work, farming, growth or cutting of vegetation, shadows and traffic. A new orthoimage had to be produced with the same accuracy and resolution (one pixel or 0.8 m on the ground). Only the derivation of orientation data for the new image by means of the existing data is carried out here.

5.1 *Description of the data*

Test site

The selected area is an open country site in the very north of Denmark. A small village is situated in the middle of the area, and a highway is crossing the area from south to north. Many other roads exist in the test site. The terrain is relatively flat and the height differences are not much bigger than ± 20 m.

New aerial image

The new aerial image was taken in June 1997 by a wide-angle camera from a flying height of 4100 m and the aerial image covers an area of approximately 38 km^2. The colour image was scanned with 30 μm (pixel size) and 24 bit (colour depth). This resulted in 177 Mb of data. An image coordinate system was established by measuring fiducial marks followed by an affine transformation onto their calibrated coordinates.

Orthoimage

The orthoimage is based on colour photography taken in June 1995. The scale of the wide-angle photographs was 1:25000. From the images a height model was generated by means of correlation techniques. The automatically derived heights were improved by means of heights and structure lines taken from a topographic map database. Further editing included 'manual' measurements by an operator under stereovision. The orthoimages were then generated with a pixel size of 0.8 m on the ground. One orthoimage covers an area of 2 km × 3 km, four of these orthoimages are used in this test. The amount of data is 110 Mb.

Map data

The map data used in this test are from the Danish topographic base map. This so-called TOP10DK covers the whole country and the dataset will be updated in a five years interval. It was produced from aerial photography 1 : 25 000 and the accuracy of well-defined points is quoted as $\sigma = 1$ m both in position and height. The TOP10DK is topologically structured which means that the linear objects are connected and area-like objects are stored as closed polygons. Several objects form a theme and the intersections of the linear objects of one theme form a continuous network. The theme "Traffic" consists of seven different objects (highway, motorway, road over 6 m in width, road 3–6 m in width, other road, path, railway).

In this investigation the intersections of the object "Road 3–6 m" with the same object and with two other objects (Road over 6 m, other road) are used as the "points of interest" and patches in the aerial image and the orthoimage were extracted and then used for the finding of corresponding pixels. Fig. 1 shows the automatically extracted road crosses after some thinning. Their YX- and Z-coordinates in the Danish reference system 34 are used in the further processing.

The topographic map and the orthoimage data form the "Existing database" from which the orientation parameters of the new aerial image are derived. The database covers only 63 % of the area of the new aerial image and this condition will reduce the accuracy of the exterior orientation somewhat.

5.2 *Extraction of image patches*

The extraction of the patches in the orthoimage requires the transformation of the ground coordinates into pixel coordinates. The coordinates of the reference point (origo) and the pixel size have to be known. The size of the orthoimage patch is selected with 31 × 31 pixels, which corresponds to 25 m × 25 m in the nature. With these dimensions road crossings and its surroundings will be included in the patches. The extraction of corresponding patches in the aerial image requires the approximate

Fig. 1: Top10DK with selected road crossings.
The small circles indicate the automatically extracted road crossings. They were found by searching in the database after the same coordinates in the three objects "Road 3–6 m in width", "Road over 6 m in width" and "Other road". A thinning of the data was applied in order to assure an equal density of patches.

values of the exterior orientation. The centre of the patches is calculated using the collinearity equations and a transformation from the image coordinate system to the scanner system. The parameters of this transformation have to be known from the scanning of images which includes the automatic measuring of the fiducial marks and an affine transformation. The dimensions of the patch were selected in this investigation with 61 × 61 pixels corresponding to about 50 m × 50 m on the ground. In that search area the same road crossing has to be contained. Otherwise mismatches will occur. This means also that the approximations for the longitudinal and lateral tilts of the image have to be known with an accuracy of about 0.2 gon.

This accuracy can be achieved by means of a multi-antenna Global Positioning System (GPS) or a low-cost Inertial Measuring Unit (IMU).

Fig. 2 shows some pairs of image patches. A comparison shows big differences in some patches, which resulted in low correlation coefficients.

5.3 *Calculation of the exterior orientation with automatically extracted image patches*

The calculation of the exterior orientation of an aerial image is carried out by means of the AAU-program "EO". It is based on the collinearity equation and uses difference-quotients instead of differential quotients in the design matrix. The approximations of the unknowns are improved from iteration to iteration and the computation stops when the corrections are small enough. Weights are introduced according to size of the residuals and the number of iteration.

This robust adjustment works also when the measurements include several blunders. Input values are XYZ-coordinates for the perspective centre and for the direction of flight (K). The standard deviation of unit weight, the parameter of exterior orientation and the residuals at the road crosses are output in the "EO" program. In addition the residuals can be displayed graphically and information about the area covered by patches as well as the density of patches is generated.

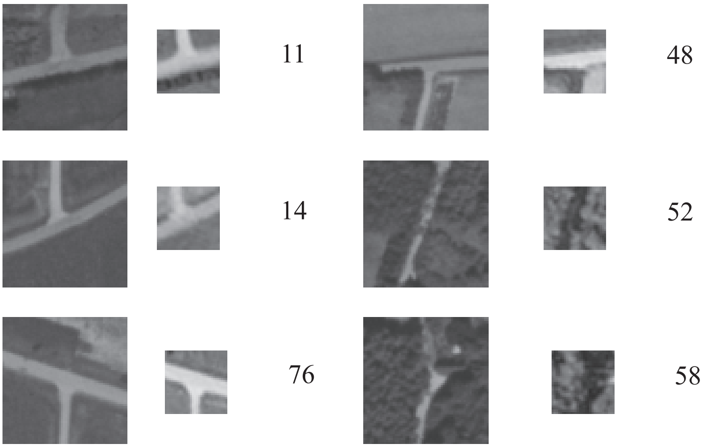

Fig. 2: Examples of image patches.
The position of best fit of a target-area within a search-area is found by means of the maximum of the correlation coefficient. The patch pairs 11, 14 and 76 have high correlation coefficients (0.9), and the patch pairs 48, 52 and 58 have very low correlation coefficients (0.4) at their position of best fit. Low correlation coefficients are caused by big differences in the image patches. They are of different dates. Human activities and changes in the vegetation and shadows will cause these differences in the images. They will very likely result in erroneous measurements.

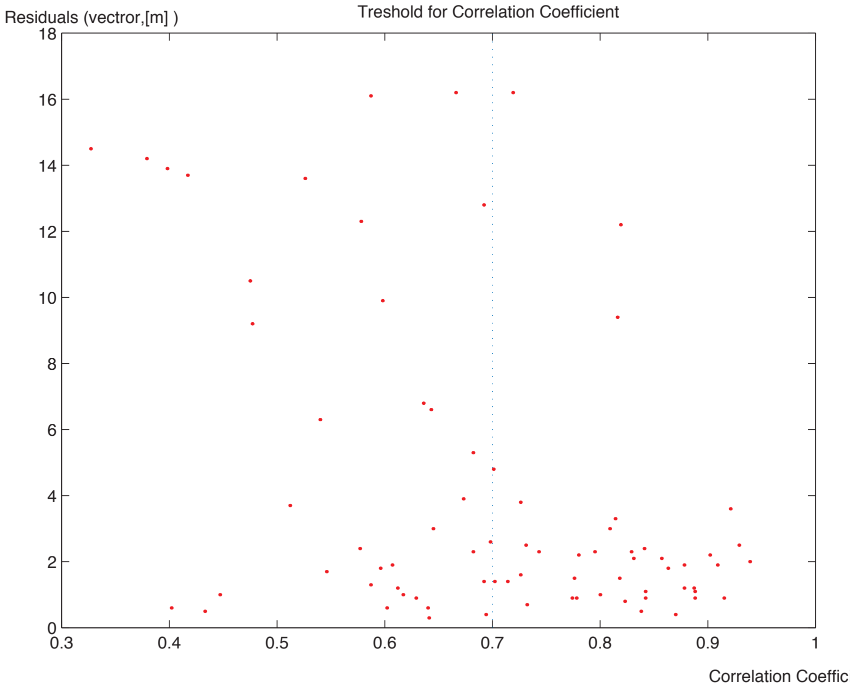

Fig. 3: Residuals after adjustment versus the maximum correlation coefficient obtained at the matching process. Small residuals can be expected when the matching occurred with high correlation coefficients. An appropriate threshold (such as S = rmax > = 0.7 in the figure) will eliminate most of the gross errors.

5.4 *Use of thresholds*

Blunders should be detected and eliminated at an earlier stage of the processing. Especially a threshold for the correlation coefficient obtained at the matching process can detect most of the blunders. This will be understood from Fig. 3 where the residuals are plotted versus the maximum correlation coefficient. It is obvious from the figure that small residuals can be expected when only such patches are processed where the matching occurred with a high correlation coefficient. If, for example, a threshold for the maximum correlation coefficient of S = rmax > = 0.7 is applied, most of the gross errors will be eliminated.

The elimination of measurements can lead to an unfavourable distribution of patches or to an insufficient number of patches. Fig. 4 depicts a graph where the eliminated points and the remaining image area are plotted versus different thresholds for the maximum correlation coefficient. The figure shows clearly, that the number of eliminated points will increase with lower correlation coefficients and that the image area covered with patches may be too small using patches with a high correlation coefficient only. Therefore, the area covered by the remaining patches should be monitored and a second threshold should be used as well. This measure could be supplemented by monitoring the point of gravity for the area covered by patches. The accuracy of the exterior orientation will be somewhat reduced if the area covered by patches is small and not centred. More investigations have to be carried out in this respect. In this investigation the threshold for the area covered by patches was set to 35 % of the aerial image. This meant that the exclusive use of patches with correlation coefficients of rmax > = 0.9 could not be done because the remaining area was less than 10 % of the aerial image.

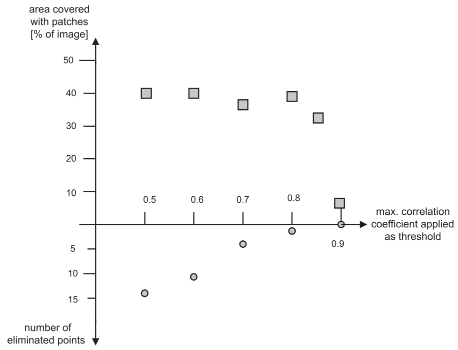

Fig. 4: Number of gross errors and the image area covered with patches at different thresholds for the maximum correlation coefficient. The selection of two thresholds (one of the correlation coefficient and one for the image area) is therefore necessary in order to derive the orientation parameters automatically. The obtained accuracy in the resection (standard deviation) was nearly the same ($\sigma = 0.9$ m) in all computations (after elimination of patches with residuals $> 3\sigma$).

5.5 *Use of robust adjustment*

The elimination of blunders can be achieved by robust adjustment. A large number of redundant measurements is, however, necessary. In this investigation weights are introduced after the first iteration according to the size of each residual and a weight function. The weights are again changed after the third iteration according to a new weight function. The derivation of weights is done after the functions given in Albertz 1989.

5.6 *Combination of thresholds and robust adjustment*

From the investigations it became clear, that the automatic measurement of extracted road crossings included a relatively large number of blunders. However, the number of blunders can be reduced if thresholds for the maximum correlation coefficient are applied. The number of usable patches will be reduced and it has to be checked if the remaining patches cover a sufficient large area of the aerial image.

Other conditions to be fulfilled are the distribution of patches over the image (especially in the corners of the image) and the position of the area's point of gravity. If all of these specified thresholds are applied the calculation of the exterior orientation will start using robust adjustment. The remaining few blunders will be down-weighted and the calculation delivers results for the exterior orientation parameters after a few iterations. This approach of combining several thresholds and robust adjustment was finally used for the derivation of the exterior orientation. In the final calculations the following thresholds were used:

Maximum correlation coefficient:
$S1 > = 0.7$
Image area covered by patches: $S2 > = 35\,\%$
Number of image corner-squares with patches: $S3 > = 3$
Centre of gravity: $S4 < = 2$ cm

When automating the process the "traffic light" principle may be applied. It means that the program should display 'green light' if the above-mentioned conditions are fulfilled. The obtained results under these conditions were the following:
Number of patches at the beginning: 78
Number of remaining patches: 37
Number of iterations: 5
Standard deviation of residuals: 0.34 m (0.4 pixel)
Orientation parameters: $\omega = 0.0624$ gon,
$\phi = 1.4824$ gon, $\kappa = 1.7891$ gon,
$Y = 341\ 949.9$ m, $X = -230\ 601.5$ m,
$Z = 4\ 201.0$ m

Fig. 5 shows the distribution of patches, the centre of gravity and the residuals at the used patches.

6 Evaluation of the results

The goal in this investigation has been an automatic orientation of aerial images and their use in the automated production of new orthoimages. Orthoimages and vector map data of an older date have to be at disposal. It is shown that such automation is possible and that orientation data can be derived. The achievable accuracy depends on the quality of the existing data (orthoimage and vector map) and the residuals of the orientation should be of the same size as the errors of the old database material.

In the test with practical data the calculated standard deviation (sigma naught) was 0.34 m or 0.4 pixel only. This means, that the residuals are small enough and the calculated exterior orientation can be used to produce orthoimages of the same quality as the existing (old) orthoimages. A comparison with the reference values of the OEEPE test material (Höhle, J. 1999a) gives also some answers about the achieved accuracy. The differences in the perspective centre coordinates are $\Delta Y = 3.2$ m, $\Delta X = 0.7$ m and $\Delta Z = 3.9$ m. These deviations are in the accuracy of the reference data ($\sigma_Y = 3.6$ m, $\sigma_X = 2.6$ m, $\sigma_Z = 1.0$ m). Previously in Höhle, J. 1999c published results (based on a manual extraction of a few road crossings) correspond even better to the results of this investigation: The deviations were $\Delta Y = 1.6$ m, $\Delta X = 1.2$ m, $\Delta Z = 0.5$ m only. The angles could not be compared because a different rotation matrix was applied. The differences in the perspective centre coordinates are rather big, but the correlation between the parameters will compensate the deviations somewhat.

In the above-mentioned OEEPE test 25 checkpoints had to be determined and the results of three authors were compared. The mean standard deviations were $\sigma_X = 0.9$ m (or 1.1 pixel) and $\sigma_Y = 0.6$ m (or 0.8 pixels) only. This is a relative accuracy of three independent determinations. It has to be mentioned that an absolute accuracy of the orthoimage is difficult to determine. It can be assumed that about the same accuracy as in the old orthoimage can be achieved by an automated process.

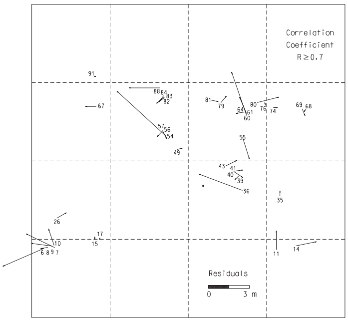

Fig. 5: Results from combining a threshold for the maximum correlation coefficient (S > = 0.7) with robust adjustment. The remaining measurements are distributed over the whole image and cover 37% of the image. A sufficient number of points remain in the corners of the image. The gross errors are down-weighted in the calculation of the exterior orientation.

7 Conclusion

This investigation proves that automation of the exterior orientation of aerial images is possible and the process of a fully automatic orthoimage production is at hands. The quality of the new orthoimage will be about the same as of the existing orthoimages. This approach in the updating of databases with new orthoimages and new map data (derived from these new orthoimages) guarantees high "neighbouring accuracy", that means, that old and new data fit well together and the updated database is homogeneous. The proposed process avoids the aerotriangulation or the direct georeferencing by means of inertia measuring units. It is therefore less expensive and can be carried out by anyone.

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