AUTOMATED MEASUREMENT OF GROUND CONTROL OBJECTS IN LARGE SCALE AERIAL PHOTOGRAPHS

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ABSTRACT

The automated determination of the exterior orientation by using map data is tested in 1:5,000 digital aerial photographs. The applied method is area based matching with target templates derived from object types in large scale digital maps. Results comparable to manual measurements are achieved. Problems may occur in case of many similar looking nearby objects. Blunders can, however, be detected by robust estimation. If these results can be verified by further tests, the method may be profitably applied to map revision, orthophoto production, and thematic mapping.

KURZFASSUNG

Die automatische Bestimmung der äußeren Orientierung wird mittels Daten einer topographischen Datenbank und digitalen Luftbildern im Maßtab 1:5000 ausgefürt. Die angewandte Metode ist eine flächenbasierte Zuordnung von Bildausschnitten und Mustermatrizen, welche von verschiedenen Objekttypen in großmaßstäbigen Karten abgeleitet wurden. Die Ergebnisse sind mit denen bei manueller Messung vergleichbar. Probleme können im Falle von vielen ähnlichen und in der Nähe gelegenen Objekte auftreten. Grobe Fehler lassen sich jedoch mittels robuster Ausgleichung aufdecken. Sofern diese Resultate sich in weiteren Tests bestätigen, kann die Orientierungsmethode bei der Kartenergänzung, Orthophotoherstellung und thematische Kartierung mit Vorteil benutzt werden.

RÉSUMÉ

La définition automatique de l'orientation extérieure en utilisant les données de carte a été éprouvée dans une photographie aérienne digitale de l'échelle 1:5000. La méthode utilisée est l'assortiment basé sur surfaces acvec un garbarit de but qui dérive des types d'objects dans des cartes digitales à grande échelle. Les résultats peuvent se comparer aux opérations de mesurage manuelle. S'il y a beacoup d'objets ressamblants à proximité cela peut poser un problème. Il est quand même possible de détecter les erreurs en faisant un ajustage robuste. Si les conclusions peuvent être vérifer par plus d'épreuves, cette méthode peut être utilisée avec avantage pour les révisions des cartes, pour le production des orthophotos et la cartographie thématique.

1 INTRODUCTION

Digital image processing has made available to photogrammetry a number of techniques for automatic measurements, and in recent years the potential of automating important photogrammetric processes has been demonstrated.

The interior orientation by recognizing the pose of the digital image and measuring the fiducials is now fully automated by means of matching well known target templates and image patches [Schickler, 1995]. The relative orientation, aerotriangulation and DEM compilation processes have been automated by matching corresponding image patches or features, using highly redundant measurements [Hellwich *et al.*, 1994], [Tsingas, 1991], [Kryzstek, 1995].

More difficult are the semantic processes of exterior/absolute orientation and map compilation. Although remarkable results have been achieved in specific scenes, e.g. [Polis *et al.*, 1995], map compilation has a long way to go before the process is truly automated.

As for the exterior/absolute orientation, there are some presented approaches to solve the task. The approach presented by Förstner [Förstner, 1988] and Schickler [Schickler, 1992] uses 3-D wireframe control points, but depends on a control point data base established by the Survey Department of Nordrhein-Westfalen in Bonn, consisting mainly of roof gable points. Vosselman and Haala [Vosselman & Haala, 1992] solves the detection problem by a relational matching method using structural descriptions of large linear features like roads and rivers. Gülch [Gülch, 1994] solves the pointing problem for signalized points using region segmentation and active contour models. Heikkinen [Heikkinen, 1994] matches linear features derived from a GIS to lines detected in an operator-selected window.

A very different and promising line of research tries to integrate several sensor systems like GPS and Inertial Navigation Systems. Results reported in [Schwarz, 1995] are accuracies of 0.1-0.2 gon for the rotation angles and 1-2 metres for the position, using a low-cost system.

As of now, none of these approaches to automate the exterior/absolute orientation solve both the detection and the pointing problem without restricting constraints. Some hybrid solutions may well be possible, but are still not available. There is a tendency towards using larger structures like houses, roads and rivers. Large structures are not so sensitive to different kinds of 'noise' like vegetation, shadows, occlusions and differences in the background.

In digital photogrammetry, there is a new strategy for automatic measurements, which is very different from the strategy of analytical measurements, e.g. [Ackermann, 1995]:

- A coarse-to-fine strategy is often used. Typically, this is implemented by means of image and feature pyramids.
- By means of a very large number of redundant measurements, high accuracies can be obtained and automatic blunder detection made possible.

The proposal presented in this paper tries to combine these principles into an automated solution to the exterior/absolute orientation – including both the detection and the pointing problems – by means of large control objects (compared to the image scale used in this investigation) derived from existing digital technical/topographical maps, which are available by nationwide coverage. Both the detection and the measurement of these control objects is done by an area based matching algorithm, taking advantage of a coarse-to-fine strategy and high redundancy. The proposed approach has, however, restricting constraints that may be quite specific to our small but well-mapped Denmark.

The potential benefit is to avoid signalization, surveying, aerotriangulation and any extra equipment like GPS/INS. This proposal will be perfectly suited for use in GIS, for map revision, for monoplotting and orthophoto production, and for production of thematic maps.

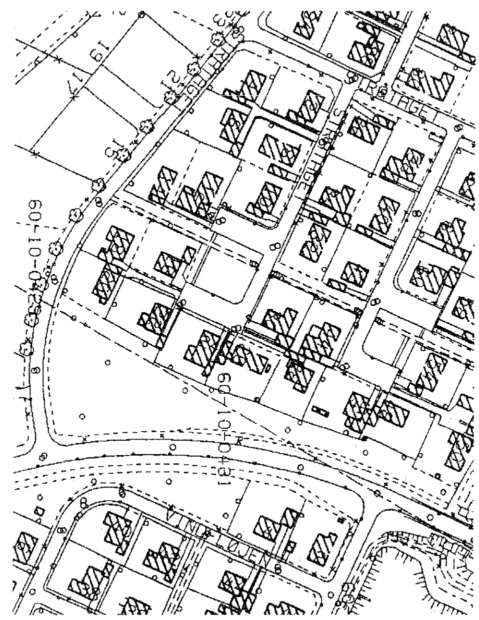

Figure 1: T3 map. Example from the model area.

2 ASPECTS OF DIGITAL TOPOGRAPHICAL/TECHNICAL MAPPING IN DENMARK

In the mid-eighties, the Danish natural gas companies required that maps delivered to them should be on digital form. This launched a development that has now resulted in a nationwide coverage of digital maps, rural areas by T0 maps and urban areas by T2 or T3 maps.

T0 maps with a σ_{XY} better than 0.7 m and σ_Z better than 1 m for well-defined points are produced from 1:30,000 to 1:20,000 imagery. The number of object types are about 19. Of specific interest here is the fact that the road centres constitute a coherent network.

T2 and T3 mapping were standardized from 1988. The number of object types are about 41 and about 51, respectively. According to the specifications, σ_{XY} is better than 0.07 m and σ_Z better than 0.15 m, if accurate height control points have been used. An example T3 map is given in figure 1.

In 1993, new so-called TK specifications including the former T0-T3 maps were agreed on. The purpose was to ensure better topological quality in the data and to ensure Z co-ordinates of full accuracy. In the T and the TK specifications as well there can be only one Z per XY and only one code per object according to a priority list.

TOP10DK is a new, fully topological map with accuracy σ_{XYZ} better than 1 m, and about 30 object types which will be available from the national cadastral authorities in nationwide coverage by 1999.

3 MEASUREMENT OF TOPOGRAPHIC GROUND CONTROL OBJECTS — METHODOLOGY

3.1 Prerequisites

From the flight plan, approximate values for the orientation parameters of the photographs are known. X_0 and Y_0 of the projection centre are assumed to be known within 1 cm in the photoscale, the flying height within 50 m, and the orientation angles within 5 gon.

In the digital topographical/technical map for the area in question, fully accurate Z co-ordinates are assumed to be available.

Of course, not all object types from topographical/technical maps are suited for area based matching. For easy target modelling, objects on the ground should be used. For easy and simple detection of the control objects, large structures like roads, footpaths and parking areas should be used. If detection and measurement of large structures is successful, it will be possible to proceed to small structures like manhole covers and gratings, for urban areas available from T2/T3 maps.

For this study, the object types road, footpath and parking areas are extracted from a topographical/technical map. It is assumed that most, but not necessarily all, road intersections can be automatically detected in the data, and that it is possible to generate a closed polygon for each target template. This has not been investigated yet, and some manual editing has done the job. When TOP10DK becomes available, however, this is probably no longer a problem.

Finally, it is assumed that the parameters of the interior orientation are available already.

3.2 Target templates

The target polygons are projected into the images by using the approximate orientation parameters from the flight plan, and a vector-to-raster conversion is performed for each image in the following way:

1. One of the polygon points is automatically chosen to be origo of the target template co-ordinate system. In this way, the X, Y **and** Z is known for the template-origo.
2. Pixels outside the polygon are given the value 100, and pixels inside the value 200.

An example is shown in figure 2.

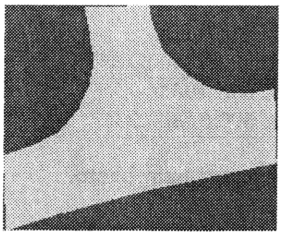

Figure 2: Target template (road intersection from the lower left of figure 1).

Splines are treated as straight lines between the registered points for reasons of computational speed. This introduces systematic errors for non-symmetric road intersections. The solution to this problem would be to compute intermediate points.

3.3 Image pyramids

A coarse-to-fine strategy is implemented by using image pyramids. The original, high-resolution image is usually referred to as level 0. In the next pyramid level, level 1, the pixel size is twice the pixel size in level 0. In this study, the pixel values in level 1 are simply computed as the mean values of the corresponding four values in level 0. Image pyramid levels 2 to 5 are built in a similar manner.

With the test data available (please refer to section 4!), there seems to be no reason to proceed any further than level 5. In level 6 even large structures like roads are fading.

3.4 Matching algorithm

The matching algorithm is designed to be running completely automatic, providing solutions to both the detection and the pointing problems by means of high redundancy in the data and a coarse-to-fine strategy. For the bundle adjustments and visualization of results, however, we have used the DEM program package MATCH-T from INPHO GmbH. The algorithm:

- For image pyramid level 5 down to level 0
  1. Project closed polygons for (road) intersections derived from a digital map into the images, using the orientation parameters available. For the first iteration, read approximate orientation parameters from a prepared file.
  2. Sample the target templates, using the nominal pixel size for the actual pyramid level. For each target template, one of the polygon points is chosen as the template origo.
  3. Compute the correlation coefficients in an appropriate search area. For the first iteration, the search area must be large, 4x4 cm^2, in the image scale.
  4. Determine subpixel image co-ordinates for all target templates by computing a least squares fit to a bivariable second-degree polynomial.
  5. Compute improved image orientation parameters by means of a robust bundle adjustment.
- Proceed to smaller ground control objects for final measurements and orientation parameter computation (this has not yet been investigated!).

In the bundle adjustments using measurements of large control objects, a priori standard deviations for horizontal and vertical control are set to twice the standard deviations for photogrammetrically well-defined points, according to the specifications. A priori standard deviations for image points are computed as the RMS of all subpixel estimations. This may not be entirely realistic, but enables automatic iterations down through the image pyramid.

4 TEST DATA

4.1 Image data

The image data used for an empirical test have been purchased for educational purposes, and are therefore easy at hand at the laboratory. Two panchromatic photographs with a 60% forward overlap at scale approximately 1:5,000, taken with a Zeiss camera of type RMK-A15/23 (c≈153 mm) have been digitized on a Zeiss/Intergraph PS1 scanner, with 8 bit radiometric resolution and 15 μm pixel size.

In the model area, 50% or less is a suburban residential area and the rest is covered by agricultural fields. A small fraction of the urban area has been built recently at the time the photos were taken.

4.2 Map data

The map data available is a digital technical T3 map from the local municipality. The map has been revised since the photographs were taken. From this map 30 (road) intersections consisting of 566 registered points have been extracted. Also, 47 arbitrarily selected from 240 available manhole covers in the same urban test area have been extracted for reference.

In figure 3 (left), the model area is shown together with the manhole covers which are used as reference points. In figure 3 (right), the positions of the extracted intersections are indicated. As can be seen, the test area covers less than 50% of the model area.

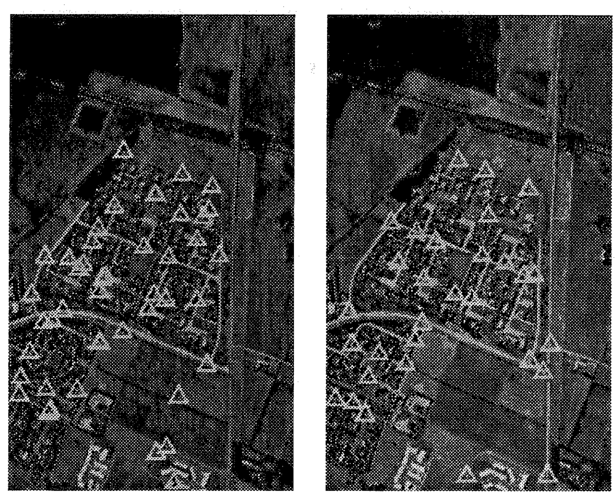

Figure 3: The model area with the manhole covers used for manual reference measurements (left), and with the positions of the extracted intersections indicated (right).

Orientation parameters	Reference values	Approximate values
$\omega^1, \phi^1, \kappa^1$ [gon]	1.4239, 2.7912, 97.2435	0.0, 0.0, 100.0
X_0^1, Y_0^1, Z_0^1 [m]	778.975, 849.507, 787.408	800.0, 800.0, 800.0
$\omega^2, \phi^2, \kappa^2$ [gon]	1.8705, 3.5164, 96.9875	0.0, 0.0, 100.0
X_0^2, Y_0^2, Z_0^2 [m]	735.269, 318.586, 784.530	700.0, 300.0, 800.0

Table 1: Reference and starting approximate values for the left and right photo.

5 EMPIRICAL TEST SETUP

5.1 Interior orientation and reference exterior orientation

The fiducials have been measured by means of the semi-automatic capabilities of MATCH-T. The whole procedure takes only a few seconds. Affine transformations were used, and the resulting σ_0 was 1.1 μm for the left image and 3.2 μm for the right image.

For the reference exterior orientation, only points within the overlap area have been measured. The orientation parameters have been computed by a bundle adjustment including manual measurements of 47 manhole covers. A priori standard deviations in the adjustment were 0.07 m for horizontal control, 0.15 m for vertical control (both corresponding to the specified standard deviations for well-defined points), and $\frac{1}{3}$ pixel = 5μm for image points. The RMS residuals were 2.7 μm in image space and 0.046 m (XY) and 0.086 m (Z) in object space.

5.2 Starting values

The approximate values for ω and ϕ are set to 0 gon, κ is in this case set to 100 gon. The X_0, Y_0 and Z_0 are rounded off to the nearest 100 m. The reference and starting approximate values are given i table 1.

The size of the search area is 81x81 pixels in level 5, and 21x21 pixels in level 4 to 0.

5.3 Evaluation of results

Results are evaluated after the robust bundle adjustment computation in each iteration, i.e. each level in the image pyramid. Firstly, the resulting image orientation parameters are compared to the reference values by a RMS calculation on the differences (RMSD) for the rotation angles and the position.

Secondly, the RMS residuals – resulting from inaccuracies in the digital map and the automatic image measurements – are computed for image space and object space (horizontal and vertical control, respectively).

6 RESULTS

If it is possible to detect possible blunders and estimate improved image orientation parameters from image points measured in level 5, with 480 μm resolution, much has been achieved. If we do not succeed in this level, we will not succeed in the higher resolution pyramid levels either.

However, a strong improvement of the orientation parameters is reached in level 5. Because of the highly redundant system, the robust bundle adjustment successfully detects 15% blunders. A closer analysis of the blunders reveals that in case of high vegetation, deep shadows or other kinds of heavy 'noise', the algorithm may detect one of the neighbouring, similar looking intersections. An example is shown in figure 4. In other cases light roofs are taken for intersections.

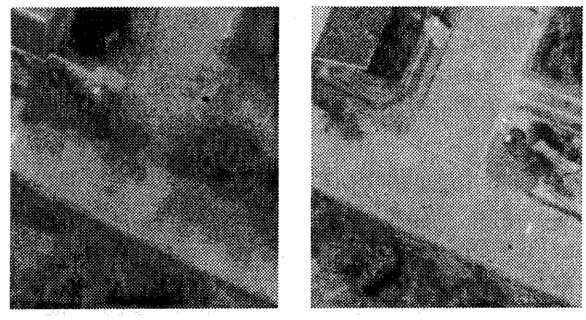

Figure 4: During the first iteration, the algorithm mixes the two intersections shown (the correct one at the left), due to the large search area in the initial search, and high vegetation.

The RMS residuals are quite low in image space, considering the 480 μm resolution, and in object space very low. The RMSD values for the orientation parameters are strongly improved. Please refer to table 2 for detailed results.

As can be seen from table 2, the iterative algorithm reaches a solution with low RMS difference and RMS residual values. There seems, however, to be some unstability in the image level iterations, which probably stems from inappropriate automatic a priori standard deviations on the image points. This is also the reason why the lowest RMS residuals in object space are reached already in level 5(!).

From level 3 to level 2, there is no improvement on the RMS differences, and the number of blunders rises from about 2% to 10%. The RMS residual values, however, are significantly improved.

Comparing the figures for level 1 and level 0, no significant improvement is obtained. This may suggest that for 1:5,000 imagery, 30 μm geometric resolution has enough information for this kind of matching, using large control structures.

One should keep in mind that there are probably systematic errors due to light/shadow conditions on the edges of the road intersections. This has not yet been investigated, but clearly, the results achieved in this test should be verified through further tests. It is evident, however, that the digital T3 map used in this test is sufficiently accurate for exterior orientation.

The processing time on a Silicon Graphics INDY workstation (133MHz R4600 CPU, 48 MB RAM) for 30 road intersections in all image levels is about 13 minutes, without any kind of optimization. This is sufficient, e.g. for overnight automatic

Type/level	RMS differences		RMS residuals		Blunders
	Angles [gon]	XYZ [m]	Image points [μm]	Control points H, V [m]	[%]
Reference	0.0000	0.000	2.7	0.046, 0.086	0.0
Approx./starting val.	2.6569	28.520	—	—	—
Level 5, 480 μm	0.4027	4.881	83.4	0.035, 0.030	15.0
Level 4, 240 μm	0.1151	1.344	35.6	0.132, 0.170	2.1
Level 3, 120 μm	0.0477	0.639	39.4	0.088, 0.141	1.9
Level 2, 60 μm	0.0475	0.620	6.6	0.107, 0.144	10.0
Level 1, 30 μm	0.0263	0.355	4.1	0.148, 0.187	2.0
Level 0, 15 μm	0.0309	0.379	3.3	0.127, 0.106	2.1

Table 2: Results for the image pyramid iterations. 'RMS differences' denote RMS differences between reference orientation parameters and automatically computed parameters in each image level. 'RMS residuals' denote RMS residuals in image and object space, and is a result of inaccuracies in the digital map and the automatic image measurements.

orientation and subsequent computation of orthophotos.

7 CONCLUSION

If the results in this test can be verified by further testing, the method presented in this paper may be profitably applied to map revision, orthophoto production, and thematic mapping. Even better results may be reached by extending the matching algorithm to smaller object types, e.g. manhole covers and gratings. The potential benefit is to avoid signalization, surveying, aerotriangulation and any extra equipment like GPS/INS.

The proposed method for exterior orientation has been applied to 1:5,000 photographs and large scale digital topographical/technical T3 maps. It seems evident that T3 maps are sufficiently accurate for this purpose.

Problems may occur in case of many similar looking road intersections. In densely built city areas, occlusions and shadows may give rise to many blunders. Pavements, of which there are very few in the test area, has no specific code in the map data, and may be found difficult or impossible to handle.

For rural areas, the presented approach should be applied to 1:25,000 photographs and T0/TK1 map data.

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