Automatic Interior Orientation of Digital Aerial Images

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Abstract
A fully operational automatic interior orientation (AUTO_IO) for digital aerial images based on a modified Hough Transform for rough localization of fiducial marks and least-squares matching for precise measurement is introduced in this paper. For cameras with fiducial mark identification symbols, e.g., as used in Leica RC30 cameras, the program is capable of determining the orientation of the photos. Results are presented using images taken by Leica and Zeiss cameras, which were scanned on different scanners in various resolutions to demonstrate the potential and robustness of the automatic IO procedure. AUTO_IO is implemented on a Helava/Leica DPW770 Digital Photogrammetric Workstation and is used in a digital production environment at swissair Photo+Surveys Ltd., Switzerland.

Introduction
With the development of higher-resolution scanners, high quality digital imagery is increasingly available. Additionally, with the progress in high performance computer hardware and software, automation of certain photogrammetric processes becomes presently possible. Techniques from image processing and computer vision have successfully been employed for facilitating automatic procedures in digital aerial images such as relative orientation (Schenk *et al.*, 1991), point transfer in photogrammetric block triangulation (Tsingas, 1995; Agouris and Schenk, 1996), exterior orientation (Schickler, 1992; Drewniok and Rohr, 1996), and the generation of digital terrain models (Krzystek, 1991). Recent developments and the state-of-the-art in automatic image orientation are summarized in Heipke (1996).

Although commercially available digital photogrammetric systems provide some automatic photogrammetric procedures, interior orientation is still often performed with manual or semi-automatic measurements of the fiducial marks (FM) in aerial images. However, due to the known shape of the FMs, which are well defined synthetic objects, their known approximate position using camera calibration data, and the good contrast at these positions, this task is very suitable for automation.

A few programs to determine the IO automatically have been already introduced in the last few years. At the Institute of Photogrammetry (University of Bonn, Germany), the Automatic Interior Orientation (AINOR) program (Schickler, 1995) was developed for the Digital Stereoplotter Phodis ST of the Carl Zeiss Company. AINOR localizes the FMs with an accuracy of better than 1/10th of a pixel without using any approximate values. After a binarization of the image, an efficient localization occurs by binary correlation using hierarchical image pyramids. The orientation of the image, which can be scanned in eight different positions, will be determined by using the asymmetric shape of the film border. The IO determination for a digital image scanned at resolution of 15 micrometres, excluding the building of the image pyramid, requires less than 30 seconds on a Silicon Graphics INDIGO (R4000). The latest version of the program and its implementation in PHODIS is introduced in Schickler and Poth (1996).

At the Surveying and Mapping Agency of Northrhine-Westfalia in Bonn, a program for automatic IO has been developed for the IS 200 image processing system of the Signum Company (Munich, Germany). The process of automatic FM detection and measurement is based on the method of binary image analysis. The FM detection is performed by comparing all labeled objects in the image to the characteristics of a real FM, while the exact position of the FM center is derived with subpixel accuracy by a parabola estimation in the original grey-value image (Knabenschuh, 1995).

Lue (1995) introduced a fully automatic digital interior orientation based on template matching techniques using a database containing fiducials of widely distributed aerial cameras. The operational software is available in the Softplotter product from Vision International of Autometric Inc.

In this paper, a fully automatic determination of IO parameters in digital aerial images is presented. The AUTO_IO (AUTOmatic Interior Orientation) program was developed to improve efficiency in the digital data production environment at Swissair Photo+Surveys Ltd., Regensdorf, Switzerland. The software is implemented on a Helava/Leica DPW770 Digital Photogrammetric Workstation. The basic concept and a preliminary version of the program was developed at the Institute of Geodesy and Photogrammetry, ETH Zurich (Haering, 1995).

Concept
The determination of IO parameters in digital aerial images is basically accomplished in six steps as illustrated in Figure 1. The main input data include the camera calibration data (image coordinates of FMs), the digital image and its pixel size, the camera type (Leica RC30, Zeiss RMK, etc.), and the film type (positive or negative). To avoid the search for the FMs over the entire image for time saving reasons, patches of 15 by 15 mm in image space are automatically extracted from the original image. For this extraction, the pixel size of the image and the calibrated FM coordinates were used to ensure the appearance of the FMs in the extracted patches. If color images are used, the extracted patches are automatically converted to greyscale. Patches from negatives are automatically inverted to positives. A rough localization is performed by a modified Hough transform (HT), while precise measurements

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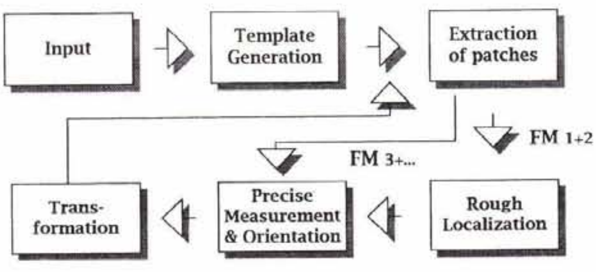

Figure 1. Workflow of the automatic interior orientation.

are carried out by least-squares template matching using initial values from the rough localization. To optimize the algorithm with respect to speed, the Hough transform is used only for the first two patches for rough localization, while the position of the other FMs are sequentially estimated from the result obtained from a two-dimensional (2-D) transformation (i.e., four or six parameters, dependent on the number of FMs used) using the previous FMs. But before matching the FMs, a template is generated related to the specified camera type using a predefined parameter file. In aerial images with FM identification symbols (e.g., see Figure 4), the orientation can be automatically estimated. Otherwise, a parameter which defines the orientation must be set. Finally, the IO parameters can be obtained by an affine transformation.

For fully automatic interior orientation, the basic conditions for the functionality of the algorithm are symmetric configuration of the FMs in the image and a rectangular image format, both of which can usually be assumed for aerial photographs. Assuming these conditions are fulfilled, the fiducials, which have to be measured, are always in the same region of the digital image, even if the image is rotated or mirrored. With a given orientation, images with any format or FM configuration can be used in AUTO_IO.

Algorithm

Modified Hough Transform with Extension

Before localization of the FMs, image patches including those FMs are extracted, using the given pixel size and the calibrated FM coordinates for approximate value estimation. The size of the extracted patches is 15 by 15 mm^2, which correspondents to 357 by 357 pixels (pixel size 42 µm), 500 by 500 pixels (30 µm), and 1000 by 1000 pixels (15 µm).

For rough localization of the FMs, an algorithm should be used which is capable of working without approximate coordinates in an efficient time frame. The modified Hough transform (HT) (Hough, 1962; Illingworth and Kittler, 1988) can fulfill the above mentioned criteria, i.e., it is suitable for transformation of image patches to localize any type of template in images (e.g., FMs) with a relatively small effort. For the sought-after synthetic pattern, a template in vector form (Figure 2a) will be created which will have vectors from the center towards each point of the pattern. This template will be placed on each point of the extracted image patch to sum up the grey values of all pixels which are located on the pattern with respect to the center of this point. Finally, all points with a sum of grey values over a specified threshold represent the center of the pattern. If only one pattern is in the search image patch, this point with the maximum is the desired center. Thus, it is also possible to find partly imaged patterns.

Using this method, problems with bright areas will occur in the image part of the aerial film close to the fiducials. These bright areas would be interpreted as many candidate fiducial centers. This can lead to false results (see also Figure 3b). Alternatively, an edge extraction and a subsequent Hough transformation of the edge image patch would give the right maximum. A better solution is the definition of an additional negative template, which was proposed by Stengele (1995) to speed up template matching for pattern recognition in topographical maps. Therefore, two templates, a skeleton and a neighborhood (Figure 2b), must be defined. The skeleton reduces the element to a one pixel line, while the neighborhood describes the figure of the element, which lays about two pixels outside of the FM border. After Hough transformations with the skeleton and the neighborhood template, the difference of both transformations yields a pixel map representing high values where the skeleton has high values and the neighborhood has low values. All other positions yield low values. The maximum can be found on the position where a bright template is on a dark background (see Figure 3c) or the opposite when using negatives.

This modification of the HT is sufficiently robust for rough localization of the FMs, even if the FM dimension is not accurately known. Both templates do not have to lay exactly at the center or at the border of the FM. The robustness of the HT cannot be guaranteed if edge extraction and an HT were to be used, because in this case a quite accurate knowledge of the shape and size of the FMs would be required.

For the rough localization by the modified HT, two improvements are implemented to speed up the computation without resampling the image patches. First, it is possible to apply the HT only to every second pixel in the x and y directions, i.e., to 25 percent of the image data. Second, the performance of the HT can be increased by using a grey level threshold, i.e., pixels with grey values under a specified threshold, e.g., black parts (grey value 0 using positive film) of the extracted image patch can be neglected. Another possible speed-up can be provided by the reduction of the number of vectors of the Hough templates. In high resolution images, templates may contain a few hundreds of vectors. For rough localization, fewer vectors are sufficient, if the vectors are well distributed over the whole template.

Orientation Estimation of Digital Aerial Images

Automatic image orientation estimation is possible if identification symbols of the FMs are available in the image, e.g., as illustrated in Figure 4 for the Leica RC20 and RC30 cameras. Currently, this option is implemented only for images from Leica cameras. To get the FM identification symbols of these images, a grey level threshold is defined in lines which are selected as vertical/horizontal and diagonal lines around the fiducial mark. The number of bright blobs (for positives) in the selected line detected by a certain threshold yields the number of lines or dots, which corresponds to the FM number (lines for FM No. 1-4, dots for FM No. 5-8).

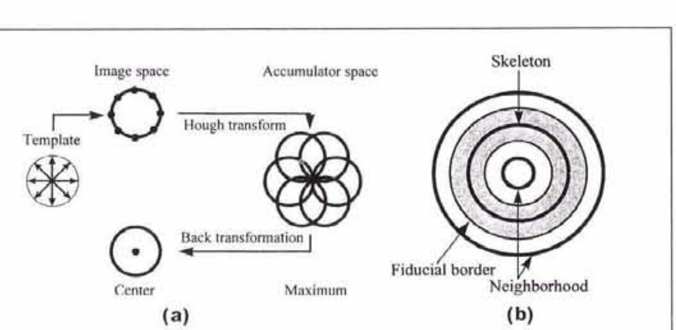

Figure 2. (a) Principle of the Hough transform. (b) Skeleton and neighborhood of the FM templates.

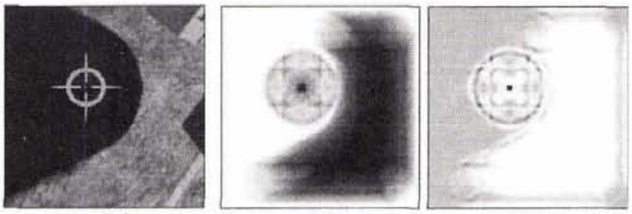

Figure 3. Results of the Hough transform. (a) Original image patch. (b) Hough transform (skeleton). (c) Extended Hough transform (skeleton minus border).

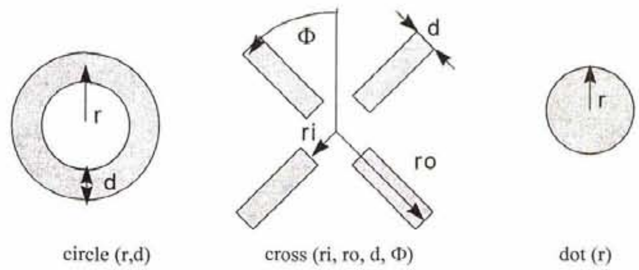

Figure 5. Elements for the description of templates.

If images are available without FM identification symbols, a parameter which defines the image orientation must be set *a priori*.

Least-Squares Matching and Templates

Precise measurements of all fiducial marks were performed by matching the extracted patches. The algorithm used is known as constrained least-squares image matching (LSM), which allows point measurements with sub-pixel accuracy, and is described in Gruen and Baltsavias (1988). In these investigations, the algorithm was used in its unconstrained mode using an artificial and ideal version of the pattern to be located as a template image (LSTM).

The accuracy of the matching algorithm is dependent on the used templates. Thus, the generation of templates for each camera type is an essential factor. To avoid the usage of image patches as templates and to avoid the management of a database with templates for several camera types in different scanned resolutions, the shape of the template for each camera type can be described with an arbitrary combination of three elements (circle, cross, and dot) in an ASCII text file as depicted in Figure 5. This description can be used for dynamic template generation. For template generation, the effects of image scanning must be simulated. Therefore, the generated artificial templates can be adapted to the real pattern (Figure 6) with image processing techniques using subsampling by a factor of 3 and Gauss filtering. The scale of the templates is given by the pixel size (input data).

Tests and Results

To demonstrate the potential and to investigate the accuracy, speed, reliability, and robustness of the AUTO_IO program, several tests were performed with different image data. For these tests, image data of five common camera types (Leica RC10, RC20, and RC30 and Zeiss RMK and UMK) were available, and were scanned in various resolutions (12.5 to 42 µm) on three scanners (Agfa Horizon, Zeiss/Intergraph PS1, and Helava DSW100). Detailed results of these investigations and tests using the preliminary version of the program are summarized in Kersten and Haering (1995). In their conclusion, the results of the automatic interior orientation obtained in these first investigations with images scanned on a photogrammetric scanner (PS1, DSW100) were in the range of 5 to 14 µm (0.2 to 0.5 pixel) for σ_0 of the affine transformation, which corresponds to results achieved with an analytical plotter. However, the σ_0 results for all images scanned on the Agfa Horizon (DTP scanner) are worse than 1 pixel; i.e., the geometric instability of the non-calibrated scanner, which could cause errors in the range of 1 to 3 pixels (Baltsavias, 1994), could not be compensated by an affine transformation.

In the production environment at Swissair Photo+Surveys, the new software was tested using digital image data from Leica RC20 and RC30 and Zeiss LMK and UMK cameras, which were scanned on the Helava/Leica DSW200 Digital Scanning Workstation with resolutions of 12.5 or 25 µm. Exemplary results for the IO determination (σ_0 of affine transformation), including elapsed time using various image data, are summarized in Table 1. For the investigations, σ_0 of the affine transformation was used as a verification criterion of the accuracy.

For comparison with the automatically obtained results, FMs of the same RC20 image data were measured semi-automatically with the Helava software. In our investigations, the semi-automatic measurements with the Helava software yielded slightly worse results (10 percent) on average than those obtained with AUTO_IO.

However, the achieved results of the automatic interior orientation obtained under production conditions are in the range of 4 to 8 µm on average. This clearly demonstrates that the accuracy potential is comparable to results obtained from analytical plotters.

The elapsed time for automatic IO of a digital image is an essential criterion in the comparison of manual or semi-automatic procedures. In general, an automatic procedure without manipulation of human operators should be faster than semi-automatic processes with user/operator interaction

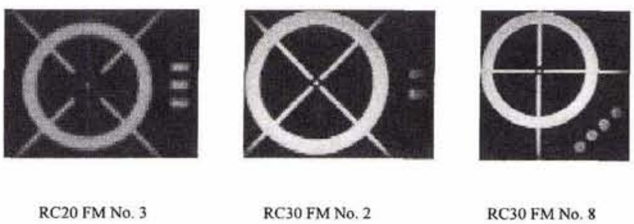

Figure 4. Identification symbols for fiducial marks in Leica cameras.

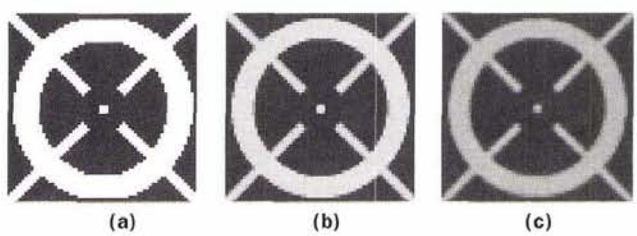

Figure 6. Sequence of image processing steps for template generation. (a) Binary template. (b) After sub-sampling. (c) After Gauss filtering.

TABLE 1. RESULTS OF FULLY AUTOMATIC IO DETERMINATION, INCLUDING ELAPSED TIME (SUN SPARC 20/71)

camera	type	resol. [μm]	# of images	# of FMs	σ_0 max. [μm]	σ_0 min. [μm]	σ_0 av. [μm]	t max. [sec]	t min. [sec]	t av. [sec]
LMK	b/w	25	14	8	7.9	3.1	5.2	8	3	6
UMK	color	12.5	3	4	5.1	2.8	4.2	26	19	23
RC20	b/w	12.5	52	4	16.2	1.4	5.3	28	4	11
RC30	b/w	25	291	8	24.0	4.7	7.7	8	3	5

due to its automatic nature. Tests were performed on a Sun SPARCstation 20/71. In our algorithm, the major part of the time is consumed with searching for the FMs in the extracted patches by HT. Therefore, the elapsed time was dependent on the extracted patch size. It was found that the program works optimally and reliably when using an extracted patch size of 15 by 15 mm (Haering, 1995). As the best result (see Table 1), for a block of 294 images from a Leica RC30 camera scanned at 25 μm, the program needed 5 seconds per image on average for automatic IO on a SUN Sparc 20. In this block, the program could not automatically determine the IO of three images due to non-centered images. These three images are not included in Table 1. The results achieved with LMK data (25-μm resolution) confirm the results for the RC30. For the RC20 data with a higher resolution of 12.5 μm, automatic IO was performed in 11 seconds per image, which is double the CPU time used for the 25-μm imagery. Color images (see UMK data in Table 1) are processed slower than black-and-white image data due to CPU time usage for merging the RGB bands of each extracted FM patch. On the other hand, in comparison to the elapsed time of AUTO_IO, the operator's measurements took approximately 40 seconds per image.

A fully automated procedure must be sufficiently robust to compensate for incorrect input data. In this program, the input of the digital image data, of the calibration file, and of the pixel size could be incorrect. Furthermore, the operator can select an incorrect camera type and the wrong film type (positive/negative). However, the quality of the digital image data is dependent on the scanning devices and the original photo material. But even in digital images with bad radiometric scanning quality (e.g., low contrast), the HT can perform a rough localization of the FMs. On the other hand, template matching is much more sensitive with respect to the radiometric quality of the images. Furthermore, images could be centered or rotated insufficiently during the scanning process or even some FMs could be partly or totally outside the scanned image, which could cause the loss of measurements but not of the affine transformation if a sufficient number of FM measurements is available. In older camera types (e.g., Leica RC10 and Zeiss RMK, LMK, and UMK cameras), the numbers of the FMs are not indicated in the image. For those types, an *a priori* definition of the image orientation must be given by the user.

Conclusions and Future Work

Today, the key for an efficient photogrammetric production environment is the degree of automation in the data production processes. In particular, interior orientation is very suitable for automation due to the well defined synthetic fiducial marks. At Swissair Photo+Surveys Ltd., the AUTO_IO program was developed for automatic determination of interior orientation of digital aerial images in color and black-and-white (negative and positive). The program is implemented on the Helava/Leica DPW770 Digital Photogrammetric Station. In several practical tests with different image data in various resolutions, it could be demonstrated that the program works accurately and efficiently with a user-friendly graphical interface to provide minimal input data for the algorithms (raster data, camera calibration data, camera type, pixel size, negative/positive, and, if FMs without identification symbols appear in the image, a parameter for the image orientation). The IO of an unlimited number of images related to one specific camera can be automatically determined in one step without any user interaction. The accuracy of the algorithm is as good as that of the semi-automatic procedures and is basically comparable to results from analytical plotters. Even with large image data sets, the speed of the measurements and IO determination is approximately 10 seconds per image, which is definitely faster than measurements by a human operator. The reliability of the algorithms depends mainly on the radiometric and geometric quality of the digitized images. But in our investigations it was possible to obtain results with fairly poor image data, which demonstrates the robustness of the Hough transform for rough localization and of the template matching for precise measurements.

For more flexibility, the program should be tested using image data from additional camera types. But in general, for a new camera type, only the FM parameter file must be created and adjusted to the specific camera. Furthermore, the detection of FM identification symbols for other camera types (e.g., Zeiss RMK TOP) must be implemented and tested. In general, the detection of FM identification symbols must become more robust due to image noise. As a further investigation, the program has to be tested for the capability of automatic measurement of images with reseau crosses. This task is more demanding than the measurement of synthetic fiducials due to a non-homogeneous background of the crosses.

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